OHIO RIVER POLLUTION SURVEY

FINAL REPORT
TO THE
OHIO RIVER COMMITTEE

SUPPLEMENT "A"

COLLECTION OF DATA ON SOURCES OF POLLUTION

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
CINCINNATI, OHIO
1942

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OFFICE OF STREAM SANITATION
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COLLECTION OF DATA ON SOURCES OF POLLUTION

Introduction

The collection of information on sources of pollution was carried out as part of the assignment of the Office of Stream Sanitation, under the direction of Senior Sanitary Engineer H. R. Crohurst, Officer in Charge. The office was also charged with the preparation of the Interim Report and later the Final Report of the Ohio River Pollution Survey. This latter work was carried out with able assistance from both pollution survey and regular staffs of the Stream Pollution Investigations Station and from the Office of the Division Engineer, Ohio River Division, Corps of Engineers, U. S. Army. Personnel of the Office of Stream Sanitation detailed to the work are listed, with their specific assignments, in Appendix VI of this Supplement.

Data on sources of pollution were obtained by engineers working at, and out of, eleven field stations maintained for varying periods of time in the offices of state health departments and of the Tennessee Valley Authority. Available information has been supplemented by information on water supply, sewage disposal and the effects of pollution, collected during actual field surveys in the many communities on the watershed under study. Visits to industrial establishments were made and data on industrial waste pollution were collected. In all instances, co-operation on the part of municipal officials has expedited the collection of field data. In the industrial surveys the information has been considered confidential, with the understanding that the data received would not be used to the detriment of any particular plant or published independently to reveal process, kinds and amounts of raw or finished products. Under this agreement, co-operation on the part of industry has generally been received. Surveys were made of some 3,700 municipalities and 1,800 industrial plants.

Special studies of industrial wastes were made in co-operation with the cities of Cincinnati and Louisville, the state of West Virginia and the Tennessee Valley Authority. These studies were of value, not only in showing the character and amount of wastes discharged at the plants studied, but also in estimating the effect of wastes from similar plants elsewhere in the basin where less detailed information was available. Correlated work included the preparation of "Industrial Waste Guides" containing information on industrial plant processes and practices, the quantities and strength of wastes for representative plants, waste treatment and recovery practices and their effectiveness in reducing pollution and a study of the cost of construction and operation of waste treatment plants both for municipal and industrial wastes. The "Industrial Waste Guides" have been made the subject of a separate supplement, "D."

A special field unit surveyed the acid mine drainage problem and determined the amount and distribution of this type of waste and the damage resulting. A presentation and analysis of this information has been made the subject of a special section of the Final Report of the Ohio River Pollution Survey and of a separate "Supplement C".

Acknowledgments

The various state health departments of the Ohio River Basin have rendered invaluable help to this survey by making available the results of their years of experience in pollution abatement work, by furnishing office space to field engineers, and by assisting in many other ways. The Health and Safety Section of the Tennessee Valley Authority has aided similarly by furnishing office space, and the results of its investigations of the streams and waste discharges in the Tennessee River Basin. Municipal officials, water and sewage treatment plant operators,and industrial officials have aided by furnishing data on waste discharges and plant operation. The cities of Cincinnati and Louisville have assisted by making available the results of consulting engineers' studies of their waste treatment problems. Among the Federal Agencies that have assisted are the U. S. Geological Survey, which furnished maps and data on stream flow, the Bureau of the Census, which furnished data on population, the U. S. Bureau of Mines which aided in the study of acid mine drainage, and the National Resources Planning Board which made available the results of its studies of the Ohio River Basin. In the preparation and criticism of "Industrial Waste Guides", assistance has been received from State, Federal, municipal and industrial officials throughout the country and from consulting engineers, equipment manufacturers, trade associations, universities and technical schools.

Instructions to Field Engineers

In a survey of the magnitude of the Ohio River Pollution Survey, using numerous (23 maximum) field engineers, more elaborate procedures are necessary to assure uniformity of results than would be the case in a survey covering a smaller or less populous area. Field surveys of approximately 5,500 municipalities and industries are involved, not including many communities and industries visited and found to be contributing no wastes of consequence.

A detailed manual of instructions was prepared and supervised training trips were taken with the eight engineers assigned during 1939 to field duty. Supplementary instructions were issued from time to time and careful checks were made of the initial reports submitted by the field engineers.

During 1940 the field staff was greatly expanded and the 1939 field engineers were used as officers in charge of field stations with the responsibility of training the new personnel. A revised manual of instructions was prepared incorporating all instructions in the original manual and supplements issued during 1939.

Miscellaneous assistance was furnished the field engineers by the Cincinnati office in the form of detailed maps, river mileages, lists of municipalities, preliminary lists of industrial plants, and various forms for note taking and for reporting. The industrial waste guides, although not all available early in the survey, were of considerable assistance in familiarizing the field engineers with industrial processes, terminology and particular points of interest from a pollution standpoint. However, municipal water supply and sewerage reporting forms and industrial wastes note taking forms were available from the beginning so that relatively uniform information was collected throughout the survey.

Memoranda and Forms

A total of seven memoranda were furnished, of which the last three or Numbers 5, 6 and 7 are reproduced as Appendices to this supplement. Copies of survey forms and sample reports are also reproduced as an appendix. The individual memoranda are as follows:

Memorandum No. 1 - "Manual for Public Health Engineers on Field Duty with State Health Departments", December 29, 1938. This memorandum was supplemented by Memorandum No. 3 and other communications and later, in April 1940, was superseded by Memorandum No. 5.

Memorandum No. 2 - "Instructions Concerning travel for Field Personnel, Expense Accounts, Reports to Central Office and Miscellaneous Matters." This memorandum deals with matters chiefly administrative in character.

Memorandum No. 3 - "Revised Manual for Public Health Engineers on Field Duty with State Health Departments", March 1939. This memorandum supplemented Memorandum No. 1 and later, in April 1940, was superseded by Memorandum No. 5.

Memorandum No. 4 - "River Mileage Index System", April 1939. This memorandum was supplemented and later, in June 1941, was superseded by Memorandum No. 6.

Memorandum No. 5 - "1940 Manual for Public Health Engineers on Field Duty with State Health Departments", April 1940. This memorandum, representing instructions prepared after experience in supervising field engineers for over a year is reproduced as Appendiz I of this supplement.

Memorandum No. 6 - "Rive Mileage Index System", June 1940. This is a revision of Memorandum No. 4 prepared in the light of experience, using the index system as originally planned and is reproduced as Appendix II of this supplement.

Memorandum No. 7 - "Damage to Industry by Acid Mine Drainage", September 1940. This memorandum on a special problem is reproduced as Appendix III of this supplement.

Survey Forms and Reports - Municipal water supply, sewerage, and industrial waste note taking and report forms and sample reports are reproduced as Appendix IV of this supplement.

A P P E N D I X   I

Memorandum No. 5
April 1940

1940 MANUAL FOR PUBLIC HEALTH ENGINEERS ON FIELD DUTY WITH STATE HEALTH DEPARTMENTS

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Memorandum No. 5

April 1940

1940 MANUAL FOR PUBLIC HEALTH ENGINEERS ON FIELD DUTY WITH STATE HEALTH DEPARTMENTS

Introduction

This memorandum is a revision of Memoranda Nos. 1 and 3 dated December 29, 1938 and February 25, 1939, respectively, outlining the general character of the work being undertaken b each of the cooperating agencies engaged in the Ohio River Pollution Survey, and methods of making field survey. Experience gained during the first year of the work has indicated the advisability of some changes in survey methods. This memo randum is intended to acquaint the new field engineers with th objectives of the survey, the methods used, and the progress t date and to explain changes in methods to the engineers now on duty.

Section 5 of the River and Harbor Act, approved August 26 1937, states:

> "that the Secretary of War is hereby authorized and directed to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited, directly or indirectly, therein and the sources and extent of such deposits, and with a view of determining the most feasible method of correcting and eliminating the pollution of these streams. The survey herein authorized shall include comprehensive investigations and studies of the various problems relating to stream pollution and abatement. In making these investigations and studies and in the development and formulation of corrective plans, the Secretary of War may, with the approval of the Secretary of the Treasury, secure the cooperation and assistance of the Public Health Service and may allot funds from the appropriation hereinafter designated to pay for such cooperation and assistance."

At the request of the Secretary of War, the Secretary of t Treasury has authorized the Public Health Service to undertake the following parts of the study:

1. Necessary laboratory examinations.

2. Collection of data on sources of pollution.

3. Determination of the character of water in the main and tributary streams.

4. Determination of the extent and cost of treatment required.

5. All other necessary studies to determine existing and future conditions bearing on pollution.

At the suggestion of the President, a three-man board was appointed to direct the survey. This includes a representative of the Corps of Engineers (Brigadier General Max. C. Tyler succeeded by Brigadier General T. M. Robins), a representative of the Public Health Service (Senior Sanitary Engineer Ralph E. Tarbett) and a non-government expert (Dr. Abel Wolman).

ORGANIZATION

The accompanying organization chart shows the various divisions of the survey.

Hydrometric Data

The Corps of Engineers possess the best facilities for measuring stream flows, has access to records of stream flow extending over a long period of years and has cooperative relationships with the U. S. Geological Survey for efficiently obtaining this essential hydrometric data. The Ohio River Division Office of the Engineer Corps is located at Cincinnati, Ohio, and the District Offices are at Pittsburgh, Pa., Huntington, W.Va., Cincinnati, Ohio, Louisville, Ky., and Nashville, Tenn. The Corps of Engineers is collecting and tabulating all necessary hydrometric data.

Laboratory Examinations

The Stream Pollution Investigations Station of the Public Health Service is making the necessary laboratory examinations of water. Laboratory examinations have been made during 1939 at the Public Health Service Station at Cincinnati, Ohio, at the floating laboratory installed on the U. S. Army Engineer quarterboat, the "Kiski", and at two mobile laboratories in automobile trailers which did most of the laboratory work on tributary streams. During 1940 the upper and lower thirds of the Ohio Basin will be covered. Three more trailers are being outfitted to aid in this work. Since the Cincinnati laboratory will not be centrally located for the 1940 work the personnel at that station will be transferred to the "Kiski".

The principal tests made are for coliform bacteria numbers, dissolved oxygen content and Biochemical Oxygen Demand. In addition, tests are made for turbidity, alkalinity or acidity, hardness, suspended and volatile matter, and nitrites. Other tests are made in special cases, particularly where industrial wastes containing objectionable chemical constituents are discharged to the stream. The Biological Studies of the principal streams are included and during 1940 some special surveys of fish life may be undertaken. An epidemiological survey of gastro-enteritis, suspected of being of water-borne origin is being made.

Sources of Pollution

The Office of Stream Sanitation, is collecting data on sources of pollution by sewage and industrial wastes on the main river and tributary streams within the basin. The method of collecting the data is briefly as follows:

1. Field engineers are assigned to cooperate with the health departments of the states in the basin.

2. The engineers submit reports on water supply and sewerage facilities and on industrial wastes on forms prepared especially for the purpose.

3. Data in the files of the State Health Departments are used to as great an extent as possible and these data are supplemented by information obtained by visiting the municipalities and industrial plants.

Details of the methods used are discussed elsewhere in the memorandum.

During 1939 eight assistant public health engineers have been in the field. Two men have been attached to each of three st te health departments, Kentucky, Ohio and West Virginia, one has been with the Tennessee Health Department and one with the Sanitation Division of the Tennessee Valley Authority. The men in Kentucky and West Virginia have worked also in the sections of Virginia and North Carolina included in the Kanawha and Big Sandy Basins. The men with the Ohio Health Department have covered the Indiana portion as well as the Ohio portion of the 1939 study area. In general, one of the men in each state covered water supply and sewerage systems and the other surveyed industrial plants discharging wastes.

The man with the Tennessee Health Department covered both fields in the Cumberland Basin in Tennessee and is now surveying the Kentucky section of that basin. The man with the Tennessee Valley Authority has surveyed industrial plants in the Tennessee Basin and assisted in special studies of various industrial wastes. Laboratory surveys have been made on both the Tennessee and Cumberland Rivers in the past few years by the T.V.A. and the Tennessee Health Department respectively, so relatively little additional laboratory work will be necessary to complete the picture.

The Works Progress Administration, working in cooperation with the U. S. Public Health Service, is carrying on a comprehensive program of sealing abandoned coal mines in eight states,

which have bituminous coal mining areas within the Ohio Basin.

Regional offices of the Public Health Service for supervision of mine sealing programs are located at the following points:

(1) Pittsburgh, Pa.
(2) Huntington, W. Va.
(3) Vincennes, Ind.
(4) Chattanooga, Tenn.

Inasmuch as the Works Progress Administration and the supervisory organization of the Public Health Service on Sealing Abandoned Coal Mines are assembling information on the total acid load for each watershed, it will not be necessary for the field workers from this office to obtain quantitative data on this type of industrial waste pollution.

OTHER COOPERATING AGENCIES

The Bureau of Fisheries, by utilizing its own mobile laboratory, may undertake studies on the effects of certain sewage disposal and industrial wastes disposal practices, on the aquatic life in the Ohio River and possibly in certain selected tributaries. This agency has loaned two boats to the survey which are being used for sample collections on the Ohio River.

Drainage Basin Committee reports of the National Resources Committee for the following eleven subdrainage basins in the Ohio Basin have been published in the document, "Drainage Basin Problems and Programs,":

1. Upper Ohio Basin
2. Beaver Basin
3. Kanawha Basin
4. Muskingum-Hocking Basin
5. Scioto Basin
6. Miami Basin
7. Big Sandy-Guyandot Basin
8. Kentucky-Licking Basin
9. Green Basin
10. Wabash Basin
11. Lower Ohio Basin

These reports are available and should be read by the field engineers.

PROCEDURE IN MAKING SOURCES OF POLLUTION SURVEY

Field surveys of the Public Health Service are conducted in close cooperation with the state health departments concerned.

In the present pollution survey the cooperative effort between Federal and State health departments will be continued. The various states are making available to the Public Health Service a vast amount of information which they have collected for their own use. The maintenance of a cordial relationship between the Public Health Service and the State health departments is very important.

The field engineer should keep constantly in mind that he should conduct himself in conformity with the standards, customs and procedures of the sanitary engineering division of that state health department with which he is cooperating. In this way he can best secure the data on the various aspects of stream pollution and at the same time be of definite assistance to the health department in advancing its program of pollution abatement. As a matter of policy, office hours of field engineers when at their official station should conform to the hours of the cooperating agency. Regular working hours in the field are usually not possible. However, when working with any other State agency, city or industrial plant, work should not be discontinued prior to the local official closing hour unless the particular assignment has been completed.

WATER SUPPLY AND SEWERAGE SURVEY

A. Purpose

Investigation of municipal water supplies, sewerage systems and sewage disposal methods of the Ohio River Pollution Survey are primarily for the purpose of:

(1) Determining the extent surface streams are required as a source of water supply, location of surface water intakes, and the effect of waste pollution on the use of such sources, and

(2) Ascertaining what pollutive substances from municipalities are being discharged directly or indirectly into surface streams, and the sources, extent and condition of such discharges, and

(3) Providing physical background data essential to formulating the most feasible corrective and control measures.

B. Scope

In general, survey data should include all municipalities with public water supplies distributed under pressure, and for water carried sewage systems. In addition, concise forms are provided for incorporated communities without water or sewage systems. Communities receiving water supplies from adjacent cities or discharging sewage to adjacent systems should be reported individually, with proper reference to the connections in question.

C. Methods of Survey

(1) General -

The field engineer should keep in mind that the primary purpose of the survey is to ascertain what pollutive substances are being discharged directly or indirectly into surface waters of the basin, the sources, and extent, and effects of such discharges, and with a view of determining the most feasible method of correcting and controlling the pollution of the streams. It is all important that field surveys reflect the influences of pollution on normal surface water uses.

For uniformity and consistency of information from various basins, field reports are submitted on specially prepared forms, devised to include a clear perspective of water and sewerage development at each municipality.

A considerable amount of required data are available from records of State Health Departments. However, in many instances, field inspections are necessary to supplement and bring these data up to date. Field contacts with municipalities are made through the State Health Departments. In this manner the established state-municipal relations are not disrupted and the field engineer is able to secure the required information from the proper municipal authorities with minimum delay.

Where underground waters are used as a source of supply, field information is primarily to determine the adequacy and dependability of such sources, and the probability of surface waters having to be used in lieu of, or to supplement, underground supplies.

Where surface waters are used as a source of public supply, the field data should be in more detail to reflect dependability, location of intakes, sources of pollution affecting such locations, treatment practices, and raw water quality as affected by waste pollution.

Field data on municipal sewerage systems should include the amount, type and strength of such waste, together with points and condition of discharges. Where sewage treatment facilities are provided, design and operating data should be obtained.

(2) Field Report Forms -

(A) General - Two forms W-1 and W-2 for water supply reports, two forms S-1 and S-2 for sewerage reports and one form WaS-1 are attached. The latter form is used only for reports on towns without water supply or sewerage systems. The other forms are used in all other cases. Forms W-1, S-1 and WaS-1 have spaces for the "Mileage Index Number" of the town. This number, which serves to locate the town with respect to the streams, is explained in Memorandum No. 4. The "Main Watershed" referred to on the forms is one of the twenty-two large divisions of the Ohio Basin. The "Sub-Watershed" is the stream (or streams in ascending order) by which drainage from the town reaches the main tributary. Other items found on more than one form are those for "State", "County", "Municipality", "Population (1930) and (1940)" and "Source of Data". The first three of these need no explanation. Tables showing lists of incorporated places by basins and their 1930 populations will be furnished. If 1940 census populations are available locally they should be included. If not, and an estimate of the 1940 population is made, the fact should be noted. Opposite "Source of Data" should be included the name and position of the informant. If the information comes from the files of the state health department, thi should be stated.

(B) Water Supply (Form W-1) -

Source of Supply: State whether from dug, drilled or driven well, spring, infiltration gallery, mine, impounding reservoir, surface stream or a combination of more than one source. If from a stream give the name of the stream. If the town is served by a supply from another town, this should be stated.

Population Served: State the total population served by the supply in the town being reported on and in areas on which no other reports are made. Do not include population served in other towns on which W-1 reports are made. It will be necessary to estimate these figures in many cases. Great accuracy is neither needed nor expected.

Average Consumption: This figure should be on the same basis as the "population served". Record to closest 10,000 gallons if less than one m.g.d. and to the closest 100,000 gallons if more than one m.g.d.

Ownership: Municipal or, if private, the name of the company. A few state, federal, county and district owned supplies will be found.

Principal Features of Treatment: Such as "coagulated, settled, filtered, chlorinated" or "lime-soda softened".

Location of Intakes: Necessary only on surface water supplies. Refer the location to some object which can be located on map such as the mouth of a stream, a bridge, a dam, the city limits, etc.

Remarks: Use this space and, if necessary, additional sheets of paper to explain any figures or information given above which may require explanation. (Use asterisk after outline data to indicate further information in "Remarks".) Give any general information or unusual facts about the supply and treatment, its adequacy, dependability, quality and the principal difficulties. If important, the effect of sewage, industrial wastes and mine drainage on surface water supplies should be discussed. This is a survey of pollution and the water supply reports are of secondary importance. More complete information is desirable on surface water supplies than on underground supplies. Indications of future need of surface water supplies because of ground water depletion or for other reasons should be mentioned. More complete reports should be made on large supplies than on small ones.

(Form W-2) -

This form is used only at towns having surface water supplies under competent laboratory control. Information on coliform organism counts in the raw water is particularly important. Unless laboratory data indicative of the sanitary quality of the raw water are available do not fill out W-2 forms merely to show such data as volume of water, turbidity, hardness, etc. Such information can be summarized under "Remarks" on W-1. A record of about five years' laboratory data should be included if available. In recording coliform organism counts it should be noted whether the figures represent most probable numbers or a coliform index.

(C) Sewerage & Sewage Treatment (Form S-1)

Type System - Such as sanitary, combined, private sewers, misused storm sewers.

Average Sewage Flow - Will be an estimate in most cases. Record to closest 10,000 gallons if less than one m.g.d. and to closest 100,000 gallons if more than one m.g.d.

Number of Outfalls - If not readily available, an estimate will suffice.

Receiving Stream - If discharge is to more than one stream, the names should be noted with estimated percent of waste to each.

Population Accessible to Sewers - Will be an estimate in most cases. Record to closest 100 if less than 10,000 and to closest 1,000 if more than 10,000.

Population Connected - Similar to population accessible.

Principal Features of Treatment - Such as "Imhoff" tanks, trickling filters, secondary settling, disinfection (summer only).

Population Connected to Treatment Plant - Important where not all sewered population is served by treatment plants.

Year Installed - Refers to treatment plant.

Rate Capacity - Based on smallest unit.

Design Population - No explanation necessary.

Remarks - Use this space and, if necessary, additional sheets to explain any figures or information given above which may require explanation. (Use asterisk after outline data to indicate further information in "Remarks"). Discuss any unique features which are of importance. If one is available include a map of the city showing the sewered areas, outfalls, water intakes, etc. Discuss any proposed improvements and include cost estimates if possible.

If the town has a sewage treatment plant and good laboratory records are available, industrial waste surveys will not be made. In such cases, note briefly what industrial wastes are treated.

Note presence or absence of sludge banks or other visual evidence of pollution. Do nuisance conditions exist at times of low flow, have complaints been made or lawsuits filed? Discuss local recreation at present and whether stream would be suitable for recreation if pollution were abated. Give any information available regarding fish and other aquatic life and whether pollution is affecting them. If surveys or studies of pollution have been made include a copy of the report, if possible, or summarize the findings.

(Form S-2) -

This form is for use only where the town has a sewage treatment plant with laboratory records. Include records of several years operation if possible. Any changes in the plant or notable changes in industrial wastes treated at the plant during the period and any factors which would make the results not representative of present conditions should be noted under "Remarks" on form S-1.

(Form WaS-1) -

This form is used only for towns with neither water supply nor sewer systems. The headings are self-explanatory.

INDUSTRIAL SURVEY

A. Purpose

The purpose of entering an industrial plant is to obtain as complete information concerning the plant and the industrial wastes discharged as is possible without detailed study. Data on past and present operation, and the management's idea of future plans and probable growth is of value. More specific purposes served by the collection of this data are: (1) to provide a basis for converting the wastes into population equivalent in terms of B.O.D., suspended solids or other quantity units which may be adopted; and (2) to assist in the determination of remedial measures and their costs. Information on industrial waste treatment or pollution remedial measures within the plant is particularly important not only in evaluating wastes from the particular plant but also in adding to information on the subject of correction of industrial waste pollution.

B. Scope

As a general policy, all industries discharging obnoxious wastes of consequence into a stream should be investigated.

Industrial plants discharging to municipal sewers which are served by municipal treatment plants need not be investigated where adequate analytical data at the treatment plant are available. Where analytical results are not available or not adequate to enable loadings to be calculated, the industrial plants should be visited. Where such plants are visited, a short note such as "tributary to municipal treatment plant" should be inserted at the top of the first report page and a similar statement should be placed under "Treatment".

Small industries such as laundries and milk plants conducting a local business in every community need not be considered since the B.O.D. of municipal sewage is considered to include these minor industries.

C. Collection of Industrial Information

(1) General -

The field engineer should keep in mind that a primary purpose of the survey is to obtain information which can be used

to determine the loading contributed by the particular source in terms of population equivalent B.O.D., suspended solids or other units, and to assist in determining the type, extent, and cost of remedial measures required.

Many items of information desired have to do with the size of the industrial plant. Measures of size include number of employees, amount of water and raw materials used, amount of product made, and amount of wastes of various kinds. One or more of these measures of size may be used to evaluate the wastes of the particular plant reported. Plant practices in the disposal of concentrated materials are very important factors in the evaluation of the wastes as discharged. Such concentrated materials include skim-milk, buttermilk and whey at milk plants, slop at distilleries, blood, paunch manure, and grease at packing plants, and skins, cores, cobs, etc. at canneries.

Plant history and forecast of future activities bearing on changes which might affect the amount or character of wastes should be solicited.

(2) Industrial Waste Guides -

Preliminary guides have been prepared for the purposes of assisting field personnel and forming the basis for more complete and accurate treatises to be prepared at a later date. To date, nine guides covering the brewing, corn and tomato canning, meat, milk, oil, paper, pulp and tanning industries have been prepared and a by-product coke guide will be distributed in the near future. It is planned to prepare guides on the distilling, textile, and metal industries.

Guides completed to date cover, in general, the following items:

1. Description of Process
2. Raw Materials and Product
3. Quantity of Wastes
4. Recovery Practices
5. Disposal Other Than to Sewer
6. Sources of Wastes
7. Character of Wastes
8. Treatment
9. Bibliography
10. Note Taking Form
11. Inspection Report
12. Flow Diagram

These guides, containing material collected from many sources, some of which is not published elsewhere, are expected to be of assistance to field engineers. They are of necessity of a preliminary nature at this time due to limited time and sources of available material. The field engineer through his contacts with the many plants of each type covered in the guides has an excellent opportunity to contribute corrections and supplementary information that will help make the later treatise valuable as an accurate reference and he is urged to do so.

(3) Entering Industrial Plants -

State health department instructions relative to entering industrial plants should be followed in all cases.

(4) Plant Locations -

Preliminary lists of plants located in the 1940 survey area are being prepared and will be distributed. The name of plant, location by state, basin, county and municipality, general classification of operation, and in some cases the product or raw material, and number of employees are given. These lists were made from data in the preliminary stream pollution survey report of the Ohio River, dated January, 1938, made by the U. S. Engineer Department. It may be necessary for the field engineer to supplement this list from state, county, local or other sources to bring it up to date. Milk plants were not included in the preliminary survey list and those of consequence will have to be located by the field engineer from the above sources.

(5) Note Taking Forms and Supplementary Information -

Note taking forms have been prepared for miscellaneous plants and 10 classified industries. A sample set of these forms is appended. Forms are intended as a guide and convenience for recording information during the actual inspection. They need not be turned in with the report but should be kept by the field engineer for his original record. The number at the right top corner of the note taking form is the classification number for the type of industrial plant and is the number to be inserted in the same place on the report form*.

* Other classified industries shown on "Map Symbols" chart may be recorded on the miscellaneous form but the report should bear the proper class number or letter.

The note taking form outlines in general the information to be obtained. Most of the outline topics are self-explanatory. However, the experience gained in using this information has developed several points which require clarification. These, together with pertinent points previously brought out in other memoranda, will be covered below. The following refers to the various note taking forms and the report form.

River Mileage Index Number, Main and Sub-Watershed - Refer to Memo. No. 6 for details. Under Main Watershed and Sub-Watershed, list receiving tributaries in order from the Main Watershed back to the outlet stream.

Plant Operation - Report days per week also. For meat plants, report the number of killing days per week or per period of time represented by the reported kill so that daily units may be estimated.

Seasonal Variation - For canneries give season dates for each product packed and report (under "Products Canned") whether or not simultaneous packing is done on what products and for how long.

Water Supply - A further breakdown should be made where multiple sources are used for any one classification. Where well supplies are used, details of pump, etc. need not be reported. Amount of water, treatment, if any, well and rock depths, if available, will be sufficient.

Raw Materials, Products - Report normal daily figures, if available, otherwise the most recent figures available, and, in addition, the capacity or maximum 24 hour operating figures. In the case of canneries, the normal daily pack at height of season, simultaneous packing, number of lines, etc. and maximum daily pack as well as seasonal packs should be reported.

Explanatory information on the units of raw materials or production should be given where possible to enable conversion to units for which strength equivalents are available. Examples are average weight of hides, capacity of cans (other than 2's, 2½'s and 10's), bottles, and cases, etc.

Wastes - Report total quantity and as much of a breakdown of the components making up this total as possible. Under "Disposal other than water carried", report such items as disposal of cuttings, peelings, etc., in the canning industry; paunch manure, blood, in the meat industry; milk

by-products; distillery slop; brewery grain (mention wet or pressed); and similar items in other industries. Mention any history of spills available. Information should be obtained on present segregation of obnoxious wastes from sanitary sewage and cooling water and if not segregated, the possibilities of making such a segregation. Where wastes are treated, as complete a story as possible under "Treatment" should be given. This is important not only for assigning a treatment factor to the wastes but as a guide to remedial practices. For example, if ponding is practiced, give details so that an estimate of its effect may be made. A statement merely saying that wastes pass through a pond to the stream does not furnish much of a basis on which to estimate a reduction figure. The tabular method of describing industrial waste treatment plants used in the Tomato Guide is recommended. Collection of cost data on treatment or remedial measures within the plant is worthy of effort. Possible sources of cost information are of interest.

Under "Analyses" report any state or local analyses available with date and plant status (flow, production, etc.) at the time. Some of these analyses, though they may seem hopelessly out of date, are valuable in many cases because of the little information available otherwise.

Outlet - Under "Gaging Possibilities", a statement of possibilities with a view to any possible future detailed studies consisting of gaging, sampling, and analysis of wastes should be made. Mention any conveniences or difficulties in this connection.

Remarks - Valuable information supplementing the outlined items and other useful information may be placed under this heading. Any condition dealing with industrial water supply or waste not already covered should be included. Individual plant characteristics, procedures or practices affecting wastes which are not typical of the industry are important. Information on past history and future plans with regards to growth or operations which might affect amount or character of wastes may be included here. General conditions in receiving streams, complaints, etc., state and local comments, recommendations, etc. should be noted.

In connection with determination of remedial measures, information is needed on conditions which might influence the selection of type of treatment, particularly as regards broad irrigation, ponding. Unless otherwise stated, it will be assumed that reported industries will have space, either their own or nearby, for the usual treatment devices but special mention should be made regarding ponding or broad irrigation possibilities.

Where it appears reasonable for a plant to connect to an existing municipal sewer system, or facilities such as interceptors which would probably be installed in connection with the building of a municipal treatment works, comments on this should be included - together with an approximation of the length of industrial sewer which would have to be laid to reach and qualifying conditions such as pumping, etc. Where such connection would appear unreasonable, a statement to that effect should be included.

Flow Diagram - A flow diagram should be prepared for each plant visited with the exception that where a diagram has previously been turned in on a similar plant it may be referred to with any supplementary changes noted to enable it to be used for the plant under consideration. The number of flow diagrams prepared should average at least one for every three industrial plants. Examples of flow diagrams for various types of plants are contained in the industrial waste guides.

D. Reports

(1) Detailed Reports -

The industrial waste report submitted to the Cincinnati office should consist of the general "I" form as a first sheet followed by the remainder of the required information in outline form on as many sheets of plain paper as is necessary and the flow diagram.

The note taking form used in the inspection may be used as a guide to the outline presentation. The extent of the informa tion desired is presented on the various note taking forms and in supplementary comments discussed in (5) "Note Taking Forms and Supplementary Information". A sample report is appended herewith.

Reports may be submitted in pencil. Flow diagrams submitted should be neatly drawn so that photostatic copies may be made directly from the sheet submitted. Too much time should not elapse between the actual inspection and the writing of the report. Completed reports should be submitted to the Cincinnati office as soon as possible. Those submitted up to the last of the month will be credited in the monthly status report.

Normally, after possible editing, four typewritten copies of reports will be made at the Cincinnati office. One of these will be sent to the field engineer; two, to the State Health Department, one for their files and the other, if they so desire, to send to the industry; and the fourth copy to be filed at Cincinnati.

(2) One-sheet remarks -

Industrial plants visited and found not to produce wastes of consequence because of the magnitude or nature of their business operations may be mentioned for record of visit by submitting a single sheet noting name, location*, type, date of visit and whatever brief remarks necessary to qualify the conclusions. Borderline plants and plants treating wastes of consequence should be given a full report.

E. Watershed Summary

Upon completion of each report or possibly of the work in each subwatershed the field engineer should place the designated information on a form summary sheet such as used in the 1939 work. Individual plants can be placed on the summary in the order in which inspections are made. However, upon completion of a main watershed, industries should be numbered for recopying in the Cincinnati office in the following order:-

(1) Industries on main stream from mouth to mouth of first tributary in numerical order of mileage index numbers.

(2) Name of tributary including mileage index number of mouth.

(3) Industries on tributary in numerical order of mileage index numbers.

---

* Including basin.

(4) Continue on main stream to mouth of next tributary, etc.

F. Monthly Status Reports

A monthly status report is distributed to the field engineers. It includes a table of the estimated total number of industries in each basin or part of basin by states together with the number of reports completed prior to and during the month reported and the estimated percentage of the total completed.

At the end of each month the field engineer should submit to the Cincinnati office the necessary data to establish the status of detailed reports in the sections under his jurisdicti

G. Summary

Summarizing the industrial waste survey, the field men should:

I. Complete an inspection at which time he should have:

(a) A completed note taking form.

(b) "Remarks" sufficient to cover the following:
1. Supplemental water supply or waste information.
2. Practices not typical of the industry.
3. Past history and future plans.
4. Attitude of industry.
5. Stream conditions, complaints.
6. State and local recommendations.
7. Information concerned with remedial (possible proposed) treatment.

(c) Tabular description of industrial waste treatment works.

(d) Flow diagram (except as before mentioned).

II. Complete and submit as soon as possible a report which should consist of an "I" report form, supplementary sheets, tabular waste treatment description and flow diagram.

III. Upon completion of each subwatershed prepare a watershed summary tabulation on forms to be furnished.

IV. Submit at the end of each month a table (similar to monthly status report) showing status of work in the sections under his jurisdiction.

MAP SYMBOLS

WATER SUPPLY -- SYMBOL □

Source of Supply
(Above symbol)

Surface -- R - river
L - lake
I - impounded
Ground -- W - well
S - spring
M - mine

Treatment
(Inside symbol)

O - No treatment
D - Chlorination (Disinfecti
I - Iron removal
Z - Zeolite softened
L - Lime-soda softened
F - Coagulated, settled, and filtered
* - Exceptions not covered. Make note at bottom of m

SEWERAGE -- SYMBOL ○

Degree of Treatment
(Inside symbol)

O - No treatment
T - Septic tank
P - Primary treatment
C - Chemical precipitation
S - Secondary treatment
D - Chlorination (Disinfection)
Ds - Chlorination - summer only
* - Exceptions not covered. Make note at bottom of map.

Quantity
(Above symbol)

Show sewage flow in M.G.

INDUSTRIAL WASTES -- SYMBOL △

Type of Industry
(Above symbol)

1. Brewery
2. Cannery
3. Coke
4. Creamery and milk
5. Distillery
6. Oil refinery
7. Packing house (meat)
8. Paper mill and pulp
9. Steel mill
10. Tannery
11. Textile
12. Metal plating
13. Chemical plant
14. Coal mine drainage (shaded)
15. Oil field (shaded)

M Miscellaneous - make note at bottom of map
* Numerous industries, list by cities at bottom of map

Treatment
(Inside symbol)

Use same letters listed under sewerage.

APPENDIX II

Memorandum No. 6
June 1940

RIVER MILEAGE INDEX SYSTEM

Memorandum No. 6

June 1940

RIVER MILEAGE INDEX SYSTEM

Introduction

This memorandum is a revision of Memorandum No.4 dated April 1939 covering the subject of the river mileage index system. Revision and additions to the system set forth in the Supplement to Memorandum No.4 dated May 13, 1939 and other instructions are incorporated in this memorandum. The principal revision not communicated to the field engineers is to the effect that the system should be carried into the smallest tributaries or to the point being identified.

General

For the purpose of identifying points on the Ohio River and its tributaries it is common practice to make use of river mileages. In order that field men may have a uniform system for designating locations of cities, sewer outfalls, industrial plants or outfalls, waterworks intakes, dams, river crossings, sampling stations and the like, an index system involving river mileages has been devised.

Main Tributaries

The index system on the main tributaries involves the use of one or more letters to identify the main tributary basins of the Ohio River combined with a figure which represents the distance in river miles from the mouth of the main tributary at its confluence with the Ohio River. For example, Charleston, West Virginia is located on the Kanawha River 58.4 river miles above its mouth. Its index number would, therefore, be K58.4.

Table No. 1 gives the index letter or letters to be used in designating the main tributary basins of the Ohio River, and includes all Ohio River tributary basins, more than 1,000

square miles in area. To prevent confusion, where more than one letter is used to designate a main tributary, only the first letter in the river designation is capitalized. For example, Lm represents the Little Miami River.

Sub-tributaries

In applying the system to the branches of the main tributaries, the letter or letters designating the main tributary is retained and another letter or letters added to designate the branch. Points on the New River, a branch of the Kanawha, are designated by the letters KN. The mileage figure used on the branch represents the river mileage from the Ohio River. For example, the town of Claremont, West Virginia is located on the New River 28.1 river miles above its mouth. The mouth of the New River, in turn, is 97.0 river miles from the mouth of the Kanawha River. The town of Claremont, West Virginia is, therefore, 28.1 plus 97.0 or 125.1 miles by river from the Ohio, and its index number would be KN125.1.

Applying the system further, the town of Talcott is located on the Greenbrier River 16.0 miles from its mouth. The mouth of the Greenbrier River is 64.0 miles above the mouth of the New River which, in turn, is 97.0 miles above the mouth of the Kanawha River. Talcott, is therefore, 177.0 river miles from the mouth of the Kanawha River and its index number would be KNG177.0. The index system should be carried into the smallest tributaries to the point being identified. Points may be located four or five tributaries back from the main tributary.

Main Ohio River

Locations on the Ohio River proper are designated by the letters "OR" or "OL", the second letter indicating the right or left bank of the stream when facing in the direction of the current or toward the mouth.

Mileages on the Ohio River are measured from the mouth. U. S. Engineers publications state mileages on the Ohio River both from the mouth and from the Point Bridge at Pittsburgh, Pennsylvania, the source of the Ohio River, and generally work with the latter figures.

Minor Tributaries

River mileage index numbers for municipalities and industries on minor tributaries to the Ohio River should include mileage identification for the mouth of such tributaries. For example, Northup, Ohio on Raccoon Creek has index No. OR704.9 - R9.5. Similarly Bloom, Ohio on Pine Creek has index No. OR634.1 - P29.

Mileage Tables

On the Ohio River, most of the main tributaries and a few of the sub-tributaries, the U. S. Engineers have made studies which have included determination of river mileage to key points. These mileages have been taken as official and are presented on river mileage tables. By using these mileages the Ohio River Pollution Survey tables will check U. S. Engineer Data.

Maps

Watershed and sub-watershed maps have been prepared for most of the basins showing mileages at five mile intervals. Where possible U. S. Engineer mileages have been used on these maps and intermediate points determined by interpolation. Where U. S. Engineer mileages are not available, five mile intervals have been determined with a map measure and are sufficiently accurate for purposes of this survey.

Watershed Summaries

On watershed summaries, cities should be listed numerically from the mouth in accordance with reference numbers rather than alphabetically. The index numbers of sub-tributary mouths should be listed numerically with points on the main tributary. Points on the sub-tributary should be listed immediately following, or before listing the next point on the main tributary above the sub-tributary mouth.

For purposes of the summary, the index number of a city should be taken from the center of town. Where possible, index numbers of industries should be taken to the industry itself. An exception would be an industry discharging to municipal sewers in which case an index number corresponding to the center of town should be given with the letters "a", "b", etc. to differentiate between the various industries.

Table Mo. 1

Ohio River Pollution Survey

MAIN TRIBUTARIES OF THE OHIO RIVER

Tributary	Miles to Mouth Ohio River	Index Letter	State
Allegheny	981.0	A	Pennsylvania - New York
Beaver	955.6	B	Pennsylvania - Ohio
Big Sandy	663.9	Bs	Ky. - W.Va. - Va.
Cumberland	60.6	C	Ky. - Tenn.
Green	196.8	Gr	Ky. - Tenn.
Guyandot	675.8	Gy	West Virginia
Hocking	781.7	H	Ohio
Kanawha	715.3	K	W.Va. - Va. - N.C.
Kentucky	435.2	Ky	Kentucky
Licking	510.8	L	Kentucky
Little Kanawha	796.4	Lk	West Virginia
Little Miami	516.9	Lm	Ohio
Miami	489.9	Mi	Ohio - Indiana
Monongahela	981.0	Mo	Penna. - W.Va. - Md.
Muskingum	808.8	Mu	Ohio
Ohio, Minor & Direct	0-981	O	Ky. - Ill. - Ohio - W.Va.- Pa.
Saline	113.7	Sa	Illinois
Scioto	624.5	Sc	Ohio
Salt	351.1	St	Kentucky
Tennessee	46.5	T	Ky. - Tenn. - Ala. - Ga. - Miss. - N.C. - Va.
Tradewater	107.6	Tr	Kentucky
Wabash	133.0	W	Indiana - Illinois

A P P E N D I X III

Memorandum No. 7
September 1940

DAMAGE TO INDUSTRY BY ACID MINE DRAINAGE

Memorandum No. 7

September 1940

DAMAGE TO INDUSTRY BY ACID MINE DRAINAGE

Certain activities relative to damage caused by acid mine drainage are contemplated in connection with the acid mine drainage assignment of the Ohio River Pollution Survey. Inasmuch as the regular field engineers are or will be visiting industrial plants in mine drainage areas, these field men will be expected to collect certain information relative to damage to industry by acid mine drainage.

The time available for completion of the field work is limited and it is not intended, therefore, to place a time consuming burden of consequence on the field staff. Information to be collected has been confined to that which should be readily available. Continuance of this activity will depend upon experience in obtaining information of value with limited time and effort.

A survey form has been devised (I-14, sample copy attached) to assist the field engineers in collecting the desired information. This form indicates specific information to be collected relative to the neutralization of water supplies and the replacement of tubes in boilers.

There are a great many other types of damage which are of consequence and concerning which specific information may possibly be available. Space has been provided for recording such damages. In general, if an industrial plant has definite knowledge of damage, an estimate of which can be substantiated by readily available data, the information should be recorded. If the damage is intangible or not capable of accurate estimation, a note may be taken but no great time or effort should be expended in securing a figure which at best might be questioned.

A list of damages to industry by acid mine drainage generally considered is given on Table 1. Damages by acid mine drainage other than to industry such as to public water supply, agriculture, recreation, locks and dams and highway structures need not be considered by the field engineers.

TABLE 1. - Types of Damage to Industry by Acid Mine Drainage.

(* Damage covered specifically by damage to industry form)

I. Water Supply (Public, *Industrial and Railroad)
  * A. Increased chemicals
    B. Corrosion and Decreased Life
      1. Pumps, plumbing and piping
      *2. Boilers
      3. Condensers and heat exchangers
      4. Treatment equipment
    C. Acid Resisting Construction

II. River Structures
    A. Bridges and Culverts
    B. Locks and Dams
    C. Water Turbines

III. Marine Equipment
    A. Metal Barges
    B. Steamboats
      1. Hulls
      2. Boilers
    C. Other Floating Equipment
    D. Loss of time due to dry docking

IV. Elimination of Industry
    A. Textiles
    B. Food Products
    C. Other

DAMAGE TO INDUSTRY BY ACID MINE DRAINAGE

Plant______________________ State____________ Ref.No.____________

City______________ County______________ Main Watershed______________

Address______________________ Sub-watershed______________

Informant______________ Title______________ Principal Product______________

WATER SUPPLY (Neutralization only): Source Stream______________________

Gal. per day	Average	Maximum	Treatment
Cooling			
Boiler			
Other			

Chemicals Used:	Grains per Gal.	Pounds per day	Pounds per Year	Cost per lb.	Cost per Year
Cooling:					
Lime				.005	
Soda Ash				.015	
Boiler:					
Lime				.005	
Soda Ash				.015	
Other:					
Lime				.005	
Soda Ash				.015	

Total excess chemical cost (Neutralization only) - - - - - - - - - - - - - - - - - - $ ______

BOILER DAMAGES: Tubes replaced per year A ______________________

Normal replacements (With neutral raw water) per year B ______________________

Cost per tube C______________ Damage per yr. (A-B) x C - - - - - - - - - - - - $ ______

OTHER DAMAGES: ______________________

A. Nature of Damage______________________

Basis for estimate ______________________

______________________ Estimate of Damage per year - - - - - $ ______

B. Nature of Damage______________________

Basis for estimate______________________

______________________ Estimate of Damage per year - - - - - $ ______

C. Nature of Damage______________________

Basis for estimate______________________

______________________ Estimate of Damage per year - - - - - $ ______

TOTAL DAMAGE PER YEAR - ______________________ $ ______

REMARKS______________________

Survey by______________________ Date______________

A P P E N D I X IV

SAMPLE REPORTS

Sample Municipal Report

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

PUBLIC WATER SUPPLY (Not an Actual City)

State Indiana County James Mileage Index No. BlMa 126

Municipality Smithton Main Watershed Black

Source of Supply Maripas River Subwatershed Maripas

Population (1930) 21,063 (1940) 22,604 Served 22,500

Average Consumption 3.5 M.G.D. Ownership Municipal

Principal Features of Treatment Aerated, Coagulated, Settled, Filtered, Chlorinated

Date Treat. Installed 1914 Rated Capacity Plant 12.0 M.G.D.

Location of Intakes Maripas River near Graves Landing

Source of Data State Health Dept., B. D. Congrar, City Engineer

Remarks - For a number of years the State Health Dept. has urged the city to move the water intake upstream to a point above local sources of pollution. The present intake is below sources of sewage and industrial wastes from both Smithton and Bardell (see Bardell Report).

Water is impounded five miles upstream from the intake at what is known as the Portisan Reservoir. The reservoir has a drainage area of approximately 9 square miles and a capacity of 335 million gallons, which is apparently adequate during prolonged droughts. However, in 1935, the city feared a shortage and installed and used several wells. These were not entirely satisfactory because of excessive hardness and iron, and brought complaints that rural wells were being dried up because of their operation.

About 1.5 g.p.g. of alum is used for coagulation. Lime is also added at times. The filtered water usually has a chlorine residual of between 0.05 and 0.10 p.p.m. The character of the raw water is shown on Form W-2. Bacterial counts of over 25,000 per c.c. have been reported.

Survey by George Spelvin Date 8-15-40

Rev. 4/27/40

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

Public Water Supply - Raw Surface Water Tests - Monthly Summary

Year 1939 State Indiana City Smithton Watershed Black

	Water treated M.G.D.	Turbidity p.p.m.	pH	Hardness p.p.m.	Alkalinity p.p.m.	Coliform Organisms per 100 cc.	Remarks
Jan	3.41	12	7.3	212	107	4430	Coliform tests are
Feb	3.51	37	6.9	130	45	4510	presumptive only.
Mar	3.46	43	7.1	125	56	1960	
Apr	3.25	28	7.1	129	59	1900	
May	3.35	9	7.5	192	129	7116	
June	3.46	52	7.3	214	127	1927	
July	3.52	27	7.5	192	122	5340	
Aug	3.64	14	7.4	196	131	1781	
Sept	3.65	8	7.6	241	147	1000	
Oct	3.79	26	7.3	211	115	2220	
Nov	3.73	8	7.4	268	149	7627	
Dec	3.57	6	7.5	268	146	1930	
Max	3.79	52	7.6	268	149	7627	Spaces in column used as follows:
Min	3.25	6	6.9	125	45	1000	Max Min
Avg	3.53	22	7.3	198	111	3480	Average

Survey by George Spelvin

Date 9-1/40.

W-2

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

SEWERAGE (Not an Actual City)

State Indiana County James Mileage Index No. B1Ma 126

Municipality Smithton Pop.(1930) 21,063 (1940) 22,604

Type System Separate (See Remarks) Average Sewage Flow 2.2 M.G.

No. Outfalls 1 Receiving Stream Balliol Creek

Pop. Accessible to Sewers 22,500 Population Connected 22,000

Principal Features of Sewage Treatment Bar Screen, grit chamber, Imhoff tanks, trickling filters (nozzle distribution), secondary sedimentation, prechlorination, sludge beds (part covered).

Pop.Connected to Treatment 22,000 Yr.Installed 1929

Rated Capacity 5.4 M.G.D. Design Population 36,000

Source of Data State Health Department, B. D. Congrar, City Engineer

Installation Cost: Interceptors - - Treat.Plant - -

Remarks - Approximately 5 miles of sewers, principally trunk sewers have been installed with Federal aid. About 1,000 persons (possibly more) living in an area outside the city limits discharge sewage which enters the river above the water intake. To correct this situation will require a low level sewer and pumping station. Cost of such a project, for an ultimate population of 4,000 has been estimated at $150,000.

A number of lawsuits have been filed against the city in recent years because of odors from the treatment plant. A number of judgments have been rendered against the city, totaling approximately $10,000. The two most recent ones have been decided in favor of the city. In order to diminish plant odors, equipment for prechlorination of the sewage was installed at a point about 1½ miles above the plant. The plant is approximately two miles north of the city limits. Prior to construction of the existing plant, the

(Continued)

Survey by George Spelvin Date 8-15-40.

Rev. 4/27/40.

REMARKS - (Continued)

city had a plant located just north of the city. The effluent enters Balliol Creek a short distance above its confluence with the Maripas River.

At the time of inspection the plant was operating satisfactorily. The prechlorinating apparatus was in operation and only a slight odor was noticeable in the vicinity of the pumping station at the plant. The receiving stream was discolored by the plant effluent but there was no evidence of sludge deposits nor were there any odors. There was no visual evidence of the wastes in the Maripas River below the mouth of Balliol Creek.

The Maripas is considered a fair fishing stream. It is stocked by the Department of Fisheries. The Sandhurst Reservoir on the Maripas about 20 miles downstream is extensively used for all types of water recreation.

The plant has a well equipped laboratory equipped for making all standard control tests. Suspended solids, D.O. and B.O.D. tests made daily on untreated sewage and plant effluent. B.O.D. and D.O. tests made twice weekly since March, 1940 on Balliol Creek and Maripas River above and below plant.

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

SEWAGE TREATMENT PLANT RECORDS - MONTHLY SUMMARY

S-2
Rev. 4/27/40

Year 1939 State Indiana City Smithton Main watershed Black

Sub-watershed Maripas

Mo. (Ave)	Sewage flow M.G.D.	Suspended solids		Dissolved Oxygen			Biochemical Oxygen Demand				Remarks
		Raw	Final	Stream above	Temp.	Stream below	Raw Sewage	Final Sewage	Stream above	Stream below	
Jan	2.24	223	24				200	26			(ave.) 8.1 p.p.m.D.O. in Final
Feb	3.28	137	24				106	21			9.6 " " "
Mar	3.37	185	18				182	23			8.3 " " "
Apr	3.03	159	16				110	11			8.3 " " "
May	1.99	258	23				225	12			7.2 " " "
June	2.00	260	29				176	18			4.9 " " "
July	1.97	280	30				164	18			4.1 " " "
Aug	1.81	265	29				166	17			3.6 " " "
Sept	1.65	235	20				214	15			3.5 " " "
Oct	1.78	240	22				216	14			5.8 " " "
Nov	1.50	241	34				213	14			7.3 " " "
Dec	1.69	238	37				203	23			6.7 " " "
Total	26.31	2721	306				2175	212			77.4 " " "
Avg	2.19	227	25.5				181	17.7			6.45 " " "
Max	3.37	280	37				225	26			9.6 " " "
Min	1.50	137	16				106	11			3.5 " " "

Survey by George Spelvin Date 9-1-40.

S-2

Sample Industrial Waste Report

NOTE TAKING FORM

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO I-3

BY-PRODUCT COKE PLANT WASTES (*Not an actual plant*)

Plant *Consolidated Coke Co.* State *W. Va.* Ref. No. *K 623*

City *Charleston* County *Kanawha* Main Watershed *Kanawha*

Address *P.O. Box 13, Charleston, W. Va.* Sub-watershed ———

Informant *Mr. John Doe* Title *Super* Principal Product *Coke*

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	168	365	330
Maximum	168	365	340

Seasonal variation *None*

WATER SUPPLY:	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City Supply	34,600	36,000	Coag.-Sed.-Filt.-Chlor.
Industrial	Kanawha R.	500,000	700,000	None
Cooling	Kanawha R.	2.5 Mil.	3.0 Mil.	None

COAL PROCESSED DAILY *1,200 Tons*

Chemicals: Sulphuric Acid *15.6 T. - 26° Be* Sodium Hydroxide *468 lb.* Lime *1,560 lb.*

PRODUCTS:- Daily Average: Coke *840 Tons* ~~Sodium~~ Phenol~~ate~~ *1,000 lb.*

Ammonium Sulfate *12 Tons* Tar *9,600 gal.* Xylene *120 gal.* Benzene *2,400 gal.*

Toluene *240 gal.* Tar (Shipped as such) *100 %* (Processed) *0*

WASTES:- Quantity *2.8 Mil. gal. p.d.* How estimated *metered Supply quench*

Character: ~~Washing~~ *F. Cooler 378,000 gal. p.d.* Quenching *150,000 gal. p.d.*

Ammonia still waste *26,000 gal. p.d.* Cooling and condensing *2.46 Mil. g.p.d.*

Carrying benzol *18,000 gal. p.d.* Recirculating *None*

Disposal other than water carried *Spent H_2SO_4 & still residue to Slag pile*

Possible spills *no recent history* Type phenol recovery *Kappers Vapor Circulat'n*

EFFLUENT ANALYSES: Number *daily* Date — By whom *Plant Lab.*

P.P.M. Phenol: Ammonia Liquor *3021*

Ammonia still wastes *112* Per cent phenol recovered *96.5*

OUTLET: Where to *Kanawha River*

Description:	Size and Shape	Material	Location	Elevation
1.	18" Cir.	Tile	East end	Co. Property line
2.	6" Cir.	Cast iron	Rear of	quench tower
3.	6" Cir.	Tile	50' West of	pump house

Gaging possibilities *Good - weir in channel from outlets to River*

Conditions below outlet: Color *Some oils*

Turbidity *Slight* Deposits *none*

SANITARY SEWAGE: Disposal *run to Kanawha* Persons tributary *346*

REMARKS *Quench is completely enclosed Sys. Final cooler water not recirculated. No increase in capacity contemplated.*

Survey by *Howard Blank* Date *3 - 6 - 1940*

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

INDUSTRIAL WASTES

River Mileage Index No. K 62.3

Type of Plant By-product coke State W.Va.

Name of Plant Consolidated Coke Co. (Not an actual plant)

Municipality Charleston Main Watershed Kanawha

County Kanawha Subwatershed ---

Address P. O. Box 13, Charleston, W. Va.

Source of Information Mr. John Doe, Superintendent

Plant Operation:- 168 hrs.p.wk. - 365 da.p.yr.
Employees Av. office 16, plant 330
Max. office 20, plant 340

Seasonal Variation:- None

(Survey report continued on next page)

Survey by Howard Blank Date March 6, 1940

Sewered Population Equivalent Computation:-

Factors used per ton of coal carbonized per day

B.O.D. 15 Suspended solids ---

Sewered population equivalent* based on B.O.D. 18,000

Sewered population equivalent* based on suspended solids ---

Remarks: Quench is completely enclosed system.
Final cooler water not recirculated.
Koppers Vapor recirculation dephenolization system.

Computation by: M. L. Wood Date 4-15-40. Cincinnati Office

Note: This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
* Rounded to nearest 100

Consolidated Coke Co., K 62.3
Charleston, W. Va.

Water Supply-

Drinking:- from city mains. Av. 34,600. Max. 36,000 g.p.d.
Industrial:- Kanawha River. Av. 500,000. Max. 700,000 g.p.d.
Cooling:- Kanawha River. Av. 2.5. Max. 3.0 Mil. g.p.d.

Raw Materials -	Coal	1200 T.p.d.
	Sulphuric Acid (26° Be)	15.6 T.p.d.
	Caustic Soda (95%)	468 lb.p.d.
	Lime	1560 lb.p.d.

Products -	Coke	840 T.p.d.
	Crude Phenol	1,000 lb.p.d.
	Total ammonium sulphate	12 T.p.d.
	Tar	9,600 g.p.d.
	Xylene	120 g.p.d.
	Benzene	2,400 g.p.d.
	Toluene	240 g.p.d.

Napthalene is separated in final cooler and added to the crude tar. Crude tar is sold as such and not refined.

Wastes -	Total (from metered supply less loss in quenching)	2.8 mil.g.p.d.
	Final Cooler (not recirculated)	378,000 g.p.d.
	Ammonia Still Waste	26,000 g.p.d.
	Benzol Carrying	18,000 g.p.d.
	Quench water lost to atmos.	150,000 g.p.d.
	Cooling	2.46 mil.g.p.d.

Spent sulphuric acid and residue from pure still are dumped on slag pile or burned.

Phenol is recovered as crude phenol by the Koppers Vapor recirculation process.

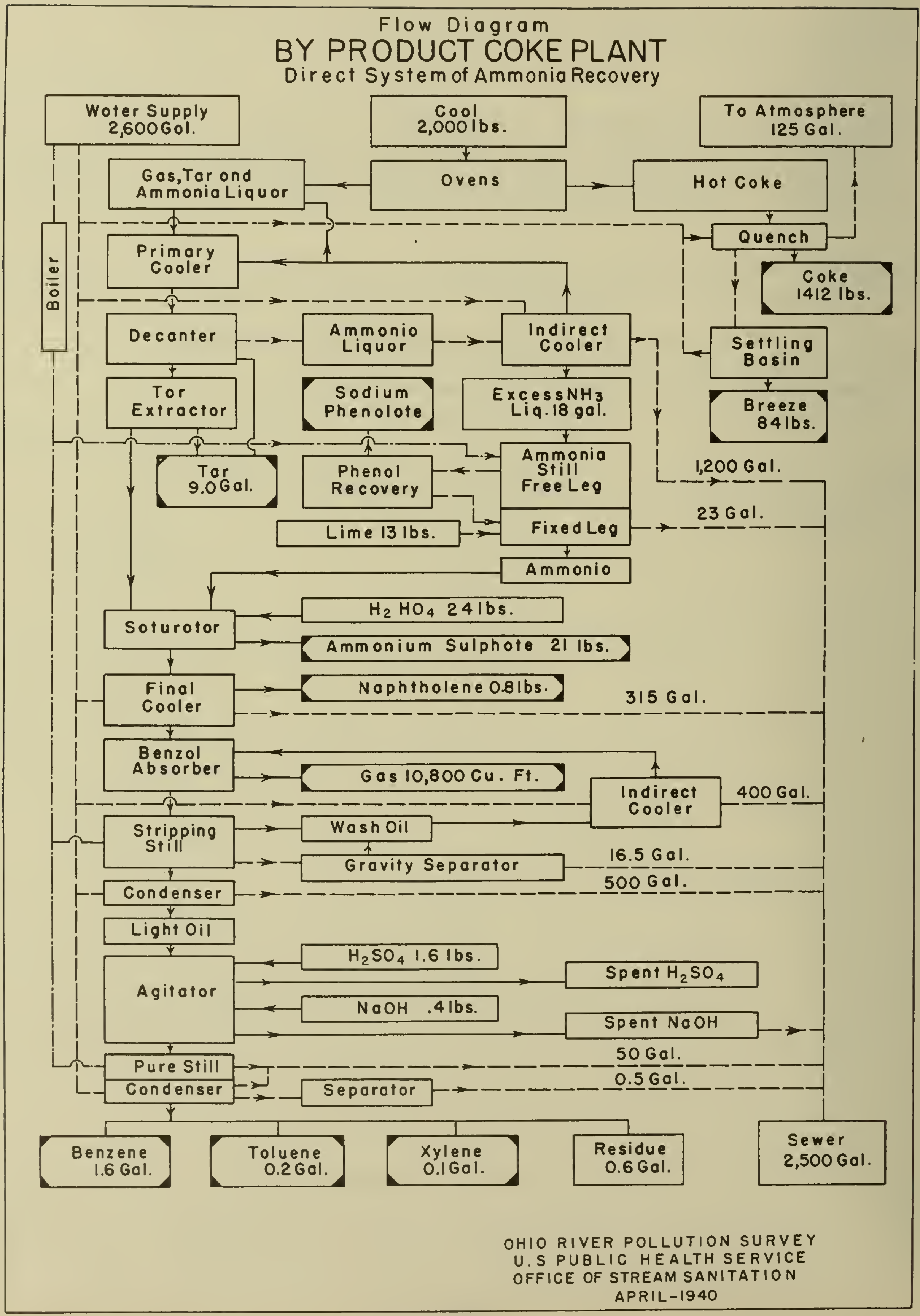
Consolidated Coke Co.

Analysis - The attached analyses show an average ammonia liquor phenol content of 3021 p.p.m. and the ammonia still waste contained 112 p.p.m. A recovery efficiency of 96.5%. Analyses are made daily by plant lab.

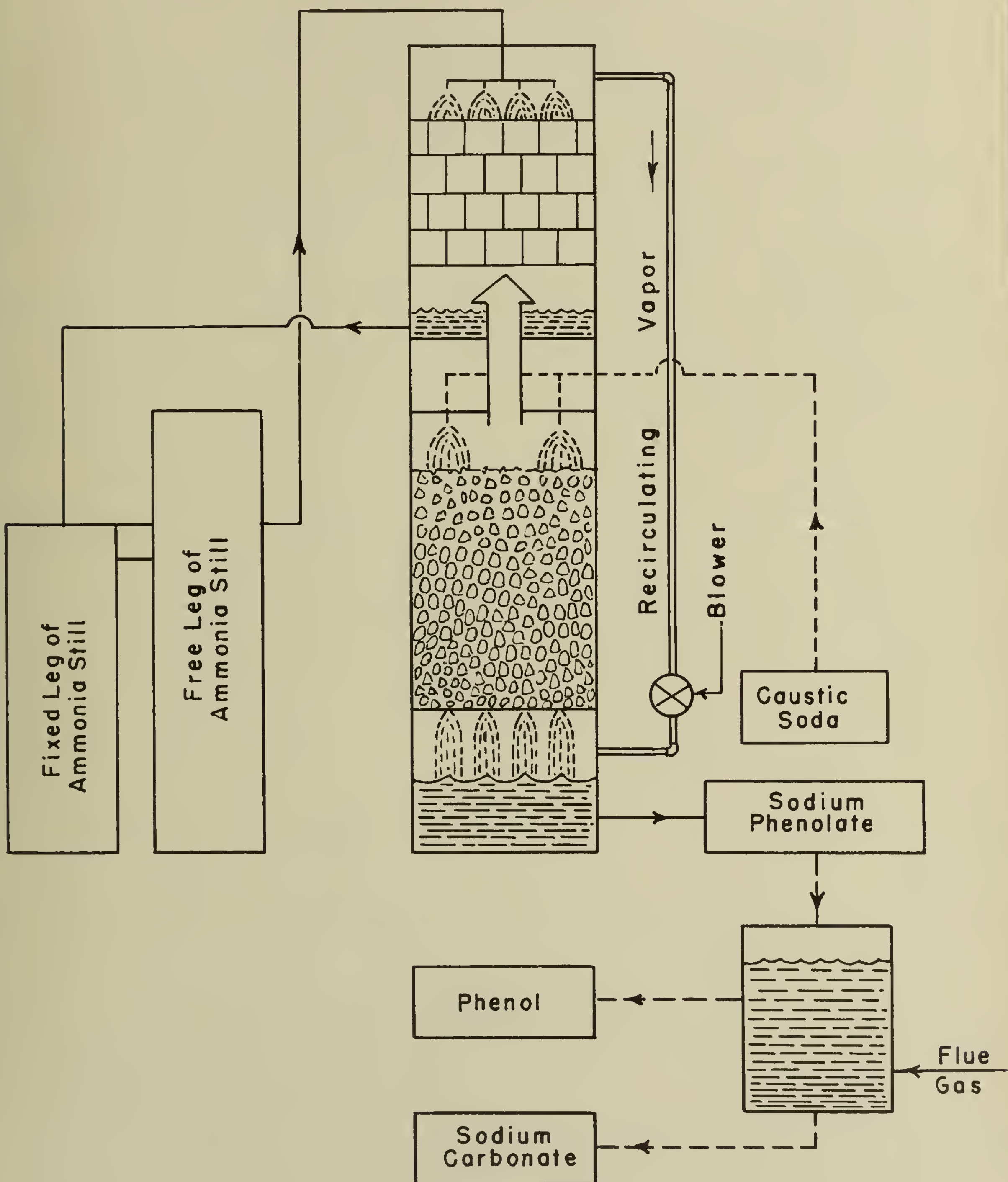
Outlets - 18" circular tile at east end of Co. property, carrying cooling water, storm water, and sanitary waste.

2 - 6" outlets carrying final cooler water, ammonia still waste, and benzol carrying waste, at rear of quench tower and 50' west of pump house. All may be measured by weirs in channel between outlet and river.

Remarks - Company does not contemplate any immediate expansion.


Flow Diagram
BY PRODUCT COKE PLANT
Direct System of Ammonia Recovery
Woter Supply 2,600 Gol.
Cool 2,000 lbs.
To Atmosphere 125 Gal.
Gas, Tar ond Ammonia Liquor
Ovens
Hot Coke
Quench
Coke 1412 lbs.
Primary Cooler
Boiler
Decanter
Ammonia Liquor
Indirect Cooler
Settling Basin
Breeze 84 lbs.
Tar Extractor
Sodium Phenolote
Excess NH_3 Liq. 18 gal.
Tar 9.0 Gal.
Phenol Recovery
Ammonia Still Free Leg
1,200 Gal.
Fixed Leg
23 Gal.
Lime 13 lbs.
Ammonia
Soturotor
H_2 HO_4 24 lbs.
Ammonium Sulphote 21 lbs.
Final Cooler
Naphtholene 0.8 lbs.
315 Gal.
Benzol Absorber
Gas 10,800 Cu. Ft.
Indirect Cooler
400 Gal.
Stripping Still
Wash Oil
Gravity Separator
16.5 Gal.
Condenser
500 Gal.
Light Oil
Agitator
H_2SO_4 1.6 lbs.
Spent H_2SO_4
NaOH .4 lbs.
Spent NaOH
Pure Still
Condenser
50 Gal.
Separator
0.5 Gal.
Benzene 1.6 Gal.
Toluene 0.2 Gal.
Xylene 0.1 Gal.
Residue 0.6 Gal.
Sewer 2,500 Gal.
OHIO RIVER POLLUTION SURVEY
U.S PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL-1940

PHENOL RECOVERY
BY
Koppers Dephenolization Progress



OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL-1940

A P P E N D I X   V

SURVEY AND MISCELLANEOUS FORMS

SURVEY AND MISCELLANEOUS FORMS

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OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

PUBLIC WATER SUPPLY

State__________County____________Mileage Index No.____________________

Municipality____________________Main Watershed____________________

Source of Supply________________Subwatershed____________________

Population (1930)________________ (1940)___________Served____________

Average Consumption_____________M.G.D. Ownership____________________

Principal Features of Treatment____________________________________

____

Date Treat.Installed_____________Rated Capacity Plant___________M.G.D.

Location of Intakes____

Source of Data____

Remarks - ____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

Survey by ________________________ Date_____________

Rev. 4/27/40

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

Public Water Supply - Raw Surface Water Tests - Monthly Summary

Year ________ State ________ City ________ Watershed ________

	Water treated M.G.D.	Turbidity p.p.m.	pH	Hardness p.p.m.	Alkalinity p.p.m.	Coliform Organisms per 100 cc.	Remarks
Jan							
Feb							
Mar							
Apr							
May							
June							
July							
Aug							
Sept							
Oct							
Nov							
Dec							
Max							Spaces in column used as follows: Max Min / Average
Min							
Avg							

Survey by ________ Date ________

W-2

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

SEWERAGE

State__________ Mileage Index No.__________

Municipality__________ Pop.(1930)________(1940)________

Type System__________ Average Sewage Flow__________M.G.D.

No. Outfalls__________Receiving Stream__________

Pop. Accessible to Sewers________Population Connected________

Principal Features of Sewage Treatment__________

Pop.Connected to Treatment__________Yr.Installed________

Rated Capacity________M.G.D. Design Population________

Source of Data__________

Installation Cost: Interceptors________Treat.Plant________

Remarks - __________

Survey by__________Date__________

Rev. 4/27/40.

S-2
Rev. 4/27/40

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

SEWAGE TREATMENT PLANT RECORDS - MONTHLY SUMMARY

Year__________ State______________ City________________________ Main watershed______________________

Sub-watershed______________________

Mo. (Ave)	Sewage flow M.G.D.	Suspended solids		Dissolved Oxygen			Biochemical Oxygen Demand				Remarks
		Raw	Final	Stream above	Temp.	Stream below	Raw Sewage	Final Sewage	Stream above	Stream below	
Jan											
Feb											
Mar											
Apr											
May											
June											
July											
Aug											
Sept											
Oct											
Nov											
Dec											
Total											
Avg											
Max											
Min											

Survey by______________________________ Date________________

S-2

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

GENERAL

- COMMUNITIES WITHOUT WATER AND SEWERAGE SYSTEMS -

State ______________________ Main Watershed ______________________

County ______________________ Subwatershed ______________________

Community ______________________ Pop.(1930) __________ (1938) __________

Incorp.or Unincorp. ______________ Informant ______________________

WATER SUPPLY (General) ______________________________________

____

____

SEWAGE DISPOSAL (Methods) ______________________________________

____

____

PROPOSED WATER AND SEWERAGE SYSTEMS ______________________________

____

____

LOCATION RESPECT STREAM, TOPOGRAPHY, ETC. ________________________

____

____

____

____

____

____

____

Survey by ______________________ Date ______________

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

INDUSTRIAL WASTES

River Mileage Index No.

Type of Plant

State

Name of Plant

Municipality

Main Watershed

County

Subwatershed

Address

Source of Information

Plant Operation:-

Seasonal Variation:-

(Survey report continued on next page)

Survey by

Date

Sewered Population Equivalent Computation:-

Factors used

B.O.D.

Suspended solids

Sewered population equivalent* based on B.O.D.

Sewered population equivalent* based on suspended solids

Remarks:

Computation by:

Date

Cincinnati Office

Note: This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
* Rounded to nearest 100

INDUSTRIAL WASTES - MISCELLANEOUS

Plant ____ State ____ Ref.No. ____

City ____ County ____ Main Watershed ____

Address ____ Sub-watershed ____

Informant ____ Title ____ Industry ____

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variations ____

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- ____

Chemicals - ____

PRODUCTS:- ____

WASTES:- Quantity ____ How estimated ____

Character:- Washings ____ Acid ____

Process ____ Alkali ____

Disposal other than water carried ____

Possible spills ____

Segregation of Strong Wastes ____

Difficulties ____

Treatment ____

Analyses:- Number ____ Date ____ By whom ____

Appearance ____

OUTLET:- Where to ____

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ____

Conditions below outlet: Color ____

Turbidity ____ Deposits ____

SANITARY SEWAGE: Disposal ____ Persons tributary ____

REMARKS ____

Survey by ____ Date ____

BREWERY WASTES

Plant ______ State ______ Ref.No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS: - Malt ______ Rice ______

Corn ______ Hops ______

Yeast ______ Other ______

PRODUCTS: - Beer ______ bbl. per brew | Brews per week: Average ______ Maximum ______

______ bbl. per year | Percent of Product Bottled ______

WASTES: - Quantity ______ How estimated ______

Brewers grain ______ Disposal ______

Spent Hops ______ Disposal ______

Yeast ______ Disposal ______

Treatment ______

Analyses: Number ______ Date ______ By whom ______

Appearance ______

OUTLET:- Where to ______

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

CANNERY WASTES

Plant ______________________ State ____________ Ref.No. ____________

City ______________ County ______________ Main Watershed ______________

Address ______________________________ Sub-watershed ______________

Informant ______________ Title ______________ Principal Product ______________

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ______________________________

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

PRODUCTS CANNED:- ______________________________

____

Normal production, height of season ______________________________ per day

WASTES:- Quantity ______________________ How estimated ______________

Washing ______________________________

Other ______________________________

____

Disposal other than water carried ______________________________

____

Possible spills ______________________________

Segregation of Strong Wastes ______________________________

Difficulties ______________________________

Treatment ______________________________

Analyses:- Number ______________ Date ______________ By whom ______________

OUTLET:- Where to ______________________________

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______________________________

Conditions below outlet: Color ______________________________

Turbidity ______________________ Deposits ______________________

SANITARY SEWAGE: Disposal ______________________ Persons tributary ______________

REMARKS ______________________________

____

Survey by ______________________ Date ______________

BY-PRODUCT COKE PLANT WASTES

Plant ____________ State ____________ Ref.No. ____________

City ____________ County ____________ Main Watershed ____________

Address ____________ Sub-watershed ____________

Informant ____________ Title ____________ Principal Product ____________

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ____________

WATER SUPPLY:	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

COAL PROCESSED DAILY ____________

Chemicals: Sulphuric Acid ____________ Sodium Hydroxide ____________ Lime ____________

PRODUCTS:- Daily Average: Coke ____________ Sodium Phenolate ____________

Ammonium Sulfate ____________ Tar ____________ Xylene ____________ Benzene ____________

Toluene ____________ Tar (Shipped as such) ____________ (Processed) ____________

WASTES:-Quantity ____________ How estimated ____________

Character: Washing ____________ Quenching ____________

Ammonia still waste ____________ Cooling and condensing ____________

Carrying benzol ____________ Recirculating ____________

Disposal other than water carried ____________

Possible spills ____________ Type phenol recovery ____________

EFFLUENT ANALYSES: Number ____________ Date ____________ By whom ____________

P.P.M. Phenol: Ammonia Liquor ____________

Ammonia still wastes ____________ Per cent phenol recovered ____________

OUTLET: Where to ____________

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ____________

Conditions below outlet: Color ____________

Turbidity ____________ Deposits ____________

SANITARY SEWAGE: Disposal ____________ Persons tributary ____________

REMARKS ____________

____

Survey by ____________ Date ____________

MILK PLANT WASTES

Plant__________ State__________ Ref.No.__________

City__________ County__________ Main Watershed__________

Address__________ Sub-Watershed__________

Informant__________ Title__________ Principal Product__________

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation__________

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Lbs. per day		Milk	Cream
Average			
Maximum			

PRODUCTS:- Bottled Milk__________ Cream__________

Butter__________ Cheese__________ Whey__________

Buttermilk__________ Milk powder__________

Skim Cond.__________ Other__________

WASTES:- Quantity__________ How estimated__________

Churn washings__________ Pasteurizer washings__________

Floor washings__________ Sour cream__________

Buttermilk__________ Whey__________

Dryer residue__________ Spills__________

Disposal other than water carried__________

Segregation of Strong Wastes__________

Difficulties__________

Treatment__________

Analyses: Number__________ Date__________ By whom__________

OUTLET:- Where to__________

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities__________

Conditions below outlet: Color__________

Turbidity__________ Deposits__________

SANITARY SEWAGE: Disposal__________ Persons tributary__________

REMARKS__________

Survey by__________ Date__________

DISTILLERY WASTES

Plant ______ State ______ Ref.No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	Hours per Week	Days per year	Plant Employees
Average			
Maximum			

Seasonal variation ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Corn ______ Rye ______

Malt ______

PRODUCTS:- Alcohol ______

Whiskey ______

Other ______

WASTES:- Quantity ______ How estimated ______

Beer Slop - Quantity ______ Screen Mesh ______

Back Slop ______ Thin Slop ______

Treatment ______

Dryer ______ Rectifying Still ______

Tailings ______ Spills ______

Analyses:- Number ______ Date ______ By whom ______

Appearance ______

OUTLET: - Where to ______

Description:	Size & shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

OIL REFINERY WASTES

Plant ______ State ______ Ref.No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Crude oil ______

Reclaimed oil ______ Other ______

PRODUCTS:- Gasoline ______ Fuel oil ______

Lub.oil ______ Other ______

WASTES:- Quantity ______ How estimated ______

Character:- Washings ______ Acid ______

Process ______ Alkali ______

Water seal ______ Other ______

Possible spills ______

Skimming basin ______

______

Analyses:- Number ______ Date ______ By whom ______

Appearance ______

OUTLET:- Where to ______

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

______

Survey by ______ Date ______

MEAT INDUSTRY WASTES

Plant________ State________ Ref.No.________

City________ County________ Main Watershed________

Address________ Sub-Watershed________

Informant________ Title________ Principal Product________

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variations________ Killing days per week________

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

KILL:- Per________	Beef	Calves	Lambs	Hogs
Normal				
1938				
Maximum				

If available, give live weights under remarks.

U. S. Inspected?________ Local Inspection?________

WASTES:- Quantity________ How estimated________

Blood recovered________

Method________

Paunch Manure________

Rendering________

Segregation of Strong Wastes________

Difficulties________

Grease traps________

Other treatment________

Analyses:- Number________ Date________ By whom________

Appearance________

Stock Pens: Area________ Stock capacity________

OUTLET:- Where to________

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities________

Conditions below outlet: Color________

Turbidity________ Deposits________

SANITARY SEWAGE: Disposal________ Persons tributary________

REMARKS________

Survey by________ Date________

PULP AND PAPER MILL WASTES

Plant ________ State ________ Ref.No. ________

City ________ County ________ Main Watershed ________

Address ________ Sub-watershed ________

Informant ________ Title ________ Principal Product ________

Plant Operation:	Hours per Week	Days per year	Plant Employees
Average			
Maximum			

Season variation ________

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Wood ________ Soda pulp ________

Sulphite pulp ________ Old paper ________

Groundwood pulp ________ Straw ________

Paper shavings ________ Rags ________

Chemicals:- Clay ________ Talc ________

Alum ________ Size ________ Soda ash ________

Caustic soda ________ Bleach ________ Dyes ________

PRODUCTS:- Capacity in T/day ________ Normal operation ________

WASTES:- Quantity ________ How estimated ________

Character ________

Disposal other than water carried ________

Dump of stock chest when change colors ________

Possible spills ________

Segregation of Strong Wastes ________

Difficulties ________

Treatment ________ Recovery practices ________

Analyses:- Number ________ Date ________ By whom ________

Appearance ________

OUTLET:- Where to ________

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ________

Conditions below outlet: Color ________

Turbidity ________ Deposits ________

SANITARY SEWAGE: Disposal ________ Persons tributary ________

REMARKS ________

Survey by ________ Date ________

STEEL MILL WASTES

Plant ______ State ______ Ref. No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Short Tons per year: - Pig Iron ______

Scrap Iron ______ Other ______

Acids:- H_2SO_4 ______

HCl ______ Other Acid ______

Alkalis:- Lime ______

Soda Ash ______ Other Alkali ______

Alkali Pickling Done? ______

PRODUCTS:- Wire & nails ______ Str. Steel ______

Galv. ______ Tin plate ______

Other ______

WASTES:- Quantity ______ How estimated ______

Pickling ______ Rinsing ______

Alkali ______ Other ______

Possible spills ______

Treatment ______

Analyses: Number ______ Date ______ By whom ______

Ave. by wt.	% Free H_2SO_4	% $FeSO_4$	or % Fe
Pickle Liquor			
Rinse Water			
Indicator			

OUTLET:- Where to ______

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

TANNERY WASTES

Plant________ State________ Ref.No.________

City________ County________ Main Watershed________

Address________ Sub-watershed________

Informant________ Title________ Principal Product________

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation________

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIALS:- Raw hides________

Chemicals:- Lime________ Sulphuric acid________

Chrome________ Dye________

Other________

PRODUCTS:-________

WASTES:- Quantity________ How estimated________

Washings________ Lime________

Acid________ Chrome________

Dye________ Other________

Possible spills________

Grease trap________

Analyses:- Number________ Date________ By whom________

Appearance________

OUTLET:- Where to________

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities________

Conditions below outlet: Color________

Turbidity________ Deposits________

SANITARY SEWAGE: Disposal________ Persons tributary________

REMARKS________

Survey by________ Date________

TEXTILE WASTES

Plant ______ State ______ Ref.No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIAL: Lbs. per Yr. Cotton ______

Wool: Grease ______ Scoured ______ Substitutes ______

Rayon ______ Silk ______

Chemicals:- Soap ______ Oils ______

Dye stuffs ______ Bleach ______

PROCESS:- Scoured ______ Dyed ______

Bleached ______

PRODUCTS:- ______

WASTES:- Quantity ______ How estimated ______

Character:- Washings ______ Acid ______

Process ______ Alkali ______

Possible spills ______

Segregation of Strong Wastes ______

Difficulties ______

Treatment ______

Analyses:- Number ______ Date ______ By whom ______

Appearance ______

OUTLET:- Where to ______

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

COAL WASHERY WASTES

Plant ______ State ______ Ref.No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______

Plant Operation:

	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variations ______

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW COAL ENTERING PLANT DAILY:- ______

Fractions: Crushed ______ Washed ______

Recovered ______ Recrushed ______

Chemicals ______

SULPHUR CONTENT:- Raw Coal ______ Refuse ______

COAL LOADED OR STORED DAILY:- ______

WASHING AND PREPARATION PROCESSES:- ______

______

WASTES:- Quantity ______ How estimated ______

Recovery Eff. ______ Dryer Eff. ______

Clean-outs:- ______

Disposal other than water carried:- ______

______

Spills or Other Wastes ______

Treatment ______

Analyses:- Number ______ Date ______ By whom ______

Appearance ______

OUTLET:- Where to ______

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE:- Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

G-1 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

OFFICE RECORD - MUNICIPAL REPORTS River Basin ______________________

City & State	County	Subwatershed	Survey made	Report Cin'ti	Forward S.H.D.

TREASURY DEPARTMENT

U. S. PUBLIC HEALTH SERVICE

State____________________

Report Letter No._________

Date______________19_____

Engineer Officer in Charge,
U. S. Public Health Service,
Ohio River Pollution Survey,
1309 Enquirer Building,
Cincinnati, Ohio.

Sir:

Attached are original reports covering factual field data on the following cities and/or industries, as indicated:

Respectfully,

____
Public Health Engineer
Assigned Field Duty

G-3 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

POPULATION IN INCORPORATED PLACES State______________ County_____________

Town Name	Basin Number	Population				
		1940	1930	1920	1910	

G-4 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO Sheet____of____

POPULATION IN UNINCORPORATED PLACES River Basin________________ State____________

County	Population in Unincorporated Places in County				% of County in Basin	Population in Unincorporated Places in Basin			
	1940	1930	1920	1910		1940	1930	1920	1910
TOTAL									

G-5 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO Sheet____of____

POPULATION SUMMARY River Basin________________ State________________

Size of Town	1940		1930		1920		1910	
	No.	Pop.	No.	Pop.	No.	Pop.	No.	Pop.
Less than 250								
250 - 499								
500 - 999								
1000 - 2499								
Sub-total								
2,500 - 4,999								
5,000 - 9,999								
10,000 - 24,999								
25,000 - 49,999								
50,000 - 99,999								
100,000 or over								
Sub-total								
Population in Incorporated Places								
Population in Unincorporated Places								
Total Population								

G-6 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO Sheet____of____

INDUSTRIES - PRELIMINARY LIST River Basin________________________ State________________

Name of Plant	City	County	Industry	Product	No. Employees

G-7 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

Sheet____of____

WATER SUPPLIES

River Basin________________ State____________

Location	State	Mileage Index Number	Population		Cons. M.G.D.	Source	Treat-ment	Owner	Remarks
			Total 1940	Served					

Form G-8

OHIO RIVER POLLUTION SURVEY – U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION – CINCINNATI, OHIO.

INDUSTRIAL WASTES - RIVER BASIN–WATERSHED SUMMARY

Mileage Index No	Name of Plant	Municipality	County	Type of Industry	Plant Employees	Operating Months	Waste–1000 gpd		Remedial Measures	City Sewer	Receiving Stream	Sewered Pop Equivalent		Flow Diagram	Date Visit	Remarks
							Cooling	Other				B O D	Susp Sol.			

SOURCES OF POLLUTION River Basin______________ State__________

Location	State	Mileage Index Number	Total 1940 Pop.	Sewerage				Population Equivalent (B.O.D.)				
								Sewage			Total	
				Pop. Con-nected	Type	Flow	Treat ment	Untrt.	Disch.	Ind. Waste	Untrt.	Disch.

G-10 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO Sheet___of___

COSTS FOR MUNICIPAL WASTE TREATMENT River Basin____________________ State______________

City	1940 Pop.	Fut. Pop.	Ind. Flow mgd.	Design Pop.	INSTALLATION COSTS				OPERATING COSTS		Remarks
					Interceptor		Treatment Plt.				
					Per cap.	Total	Primary	Second.	Primary	Second.	

G-11 OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO Sheet____of____

COSTS FOR INDUSTRIAL WASTE TREATMENT River Basin______________ State__________

Location & Name of Plant	Type of Industry	Type Treatment Proposed	Cost of Correction						
			Installation Cost				Annual Charges		
			Con-nection	Ind. Treat.	Pre-treat.	Total	Int.& Amor.	Oper.	Total

PERSONNEL

Information on sources of pollution was collected under the administrative direction of Senior Sanitary Engineer H. R. Crohurst, in charge of the Office of Stream Sanitation at Cincinnati, Ohio. The work was organized and carried out under the technical direction of Sanitary Engineer (R) Ellis S. Tisdale, with the assistance of Senior Public Health Engineer M. LeBosquet, Jr., in charge of industrial waste activities, and Passed Assistant Sanitary Engineer Mark D. Hollis, in charge of municipal water supply and sewerage activities. Assisting Mr. LeBosquet was Associate Public Health Engineer Samuel R. Weibel, and assisting Mr. Hollis was Associate Public Health Engineer Richard L. Woodward. Messrs. Weibel and Woodward also handled special assignments.

During 1940, Assistant Sanitary Engineer (R) Paul D. Haney and Assistant Sanitary Engineer (R) Paul E. Seufer were added to the staff and placed on special assignments. Assistant Sanitary Engineer (R) Ralph C. Palange and Assistant Public Health Engineer William T. Eiffert were added to the Cincinnati office. Certain field engineers, transferred to Cincinnati after completion of field assignments, assisted in the early phases of preparation of the final report.

Due to the need for experienced personnel in connection with emergency health and sanitation activities, Mr. Tisdale was transferred in March, 1941, and Mr. Hollis in April, 1941, to other duties, and the final phases of the work were supervised by Mr. LeBosquet under Mr. Crohurst's direction.

Field engineers assigned to state health departments and the Tennessee Valley Authority for the actual collection of information during 1939 were as follows:

<u>Ohio</u>
Gordon E. McCallum, Associate Public Health Engineer.
Charles D. Yaffe, Assistant Public Health Engineer.

<u>West Virginia</u>
Charles R. Keatley, Associate Public Health Engineer.
H. Gardner Bourne, Jr., Assistant Chemical Engineer.

Note: Official designations apply to the last day of each person's connection with the Ohio River Pollution Survey.

Kentucky
Archie B. Freeman, Assistant Public Health Engineer.
George D. Reed, Assistant Public Health Engineer.

Tennessee
Arvo A. Solander, Assistant Public Health Engineer.

Tennessee Valley Authority
Richard F. Poston, Associate Public Health Engineer.

During the expanded program of 1940, the 1939 field staff served as a nucleus and the field organization was as follows:

Pennsylvania - New York, Mr. Keatley in charge:
Sterling M. Clark, Assistant Sanitary Engineer (R).
Joseph E. Flanagan, Jr., Assistant Sanitary Engineer (R).
Edward N. McKinstry, Assistant Public Health Engineer.
William C. Murray, Assistant Public Health Engineer.
Emanuel H. Pearl, Assistant Public Health Engineer.
Ray Raneri, Assistant Sanitary Engineer (R).
(Following Mr. Keatley's transfer to other duties, Mr. Pearl, and later Mr. Flanagan, were placed in charge at this office.)

Ohio, Mr. Yaffe in charge:
James G. Terrill, Jr., Assistant Sanitary Engineer (R).

West Virginia, Mr. Bourne in charge:
Daniel A. Okun, Assistant Sanitary Engineer (R).

Kentucky, Mr. Freeman and Mr. Reed.

Indiana-Illinois, Mr. McCallum in charge:
Ralph J. Johnson, Assistant Sanitary Engineer (R).
Edwin B. Joseph, Assistant Sanitary Engineer (R).
Royal E. Rostenbach, Assistant Chemical Engineer.
Charles C. Spencer, Assistant Sanitary Engineer (R).
(Following Mr. McCallum's transfer to other duties, Mr. Spencer was placed in charge of this office.)

Tennessee, Mr. Solander.

Tennessee Valley Authority, Mr. Poston in charge:
Ralph Porges, Assistant Sanitary Engineer (R).

Special assignments consisted of:

1. Municipal Treatment Plant and Intercepting Sewer Costs, by Mr. Hollis.

2. Population Studies, by Mr. Woodward.

3. Preparation of Industrial Waste Guides (see Supplement "D") under the supervision of Mr. LeBosquet: by Mr. Weibel (6 guides), Mr. LeBosquet (3 guides), Mr. McCallum (2 guides), Mr. Reed (2 guides), Mr. Bourne (1 guide), and Mr. Porges (1 guide). Mr. Woodward and Mr. Palange assisted in revising the guides for the final report.

4. Industrial Waste Treatment Costs, by Mr. Weibel.

5. Acid Mine Drainage Studies (see Supplement "C") by Messrs. LeBosquet and Haney, assisted by Messrs. Palange and Rostenbach.

6. Administration of Pollution Abatement, by Mr. Seufer.

OHIO RIVER POLLUTION SURVEY

FINAL REPORT
TO THE
OHIO RIVER COMMITTEE

SUPPLEMENT "B"

ORGANIZATION AND METHODS OF LABORATORY STUDIES

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
CINCINNATI, OHIO
1942

ORGANIZATION AND METHODS OF LABORATORY STUDIES

Supplement "B" to
Final Report to the Ohio River Committee
Ohio River Pollution Survey

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
STREAM POLLUTION INVESTIGATIONS STATION
CINCINNATI, OHIO
1942

ORGANIZATION AND METHODS OF LABORATORY STUDIES

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ORGANIZATION AND METHODS OF LABORATORY STUDIES

The laboratory studies carried out in connection with the Ohio River Pollution Survey have constituted one of the three major parts of the Survey, the other two being concerned, respectively, with the collection of data on sources of pollution and with the measurement of the volume of flow of the streams in the Ohio River Basin during the period of the Survey. From the standpoint of operations, the laboratory studies have been in some respects the most difficult and complex activity connected with the Survey, as they have involved the systematic examination of practically every stream in the 204,000 square miles of territory included within the Basin, except in certain limited areas of the Scioto,* Tennessee, Cumberland and Miami watersheds, where recent laboratory observations had been carried out by other agencies.

The methods and results of the routine laboratory operations of the Survey have been described somewhat briefly in connection with the main report of the Survey, including a presentation of the results of the stream examinations in complete tabular form. Owing to the limited space available in the main report, however, it has not been practicable to give in that report certain details concerning the planning and methods of carrying out the laboratory operations of which a record would be desirable elsewhere for the benefit of those undertaking similar work in the future.

(*) See Public Health Bull. 276, U. S. Public Health Service.

Objectives of Laboratory Studies

The main objectives of the laboratory studies have been as follows:

1. To ascertain, by means of systematic laboratory tests, the sanitary quality of the waters of the main Ohio River and its tributary streams at various points throughout the entire drainage basin and especially above and below recognized sources of pollution.

2. To examine streams in the mining sections of the Basin for evidences of acid mine wastes and their effects.

3. To study, so far as practicable, certain special problems resulting from stream pollution along the Ohio River and its tributary streams, notably:

   (a) The measurable effects of mine sealing on the acidity of streams receiving mine wastes.

   (b) The presence in stream waters of substances causing tastes and odors in water supplies, notably phenolic substances causing chlorophenol tastes, which have been most commonly prevalent in water supplies of the Ohio Basin.

   (c) The presence of sludge deposits in pooled sections of the main Ohio River.

4. To observe, by methods of biological study, the effects of sewage and industrial wastes pollution on the plankton and higher aquatic life, notably fish life, in various typical streams throughout the Ohio Basin.

In undertaking a systematic examination of stream waters throughout the Ohio River Basin, it was essential to have in mind the divergent effects which variations in the flow and temperature of a stream may have on the sanitary quality of its water at different times. From the standpoint of general sanitary conditions, the more

critical flows and temperatures usually occur during the dry-weather conditions of summer, when the volumes of diluting water carried by streams are at their minimum and increased water temperatures tend to promote the more rapid bio-chemical decomposition of organic polluting materials at a time when the normal dissolved oxygen content of a stream is at its lowest level. From certain other standpoints and notably with respect to the use of streams for water supplies, more critical conditions may occur during periods of increased stream flows, especially following prolonged low water conditions.

Although every effort was made to observe stream conditions over as much of the Basin as practicable during "critical" flow periods such as above indicated, it was not feasible to carry out such observations simultaneously except over restricted areas, because each laboratory unit was limited in its coverage to a radius of about 50 miles from a particular location point. Moreover, the long periods of drought which occurred throughout the years 1939 and 1940, though facilitating the extension of laboratory observations to more areas during low-water periods than otherwise would have been possible, reduced correspondingly the opportunities for high water observations during periods of the winter and spring when these conditions normally would be expected to prevail. One advantageous circumstance which resulted from the abnormal prolongation of drought conditions through the winters of 1939 and 1940 was the opportunity thus provided for observing some streams under low water conditions both in summer and in winter, with stream temperature the only important variable to be considered as affecting the sanitary quality of the stfeams during these two different seasons.

The effects of mine wastes on streams in large sections of the Ohio River Basin devoted to soft coal mining are known in general terms, but had not been measured systematically by means of stream observations to any considerable extent prior to the present Survey. Owing to the extensive program of mine sealing which has been in progress in different parts of the Basin, it was considered especially important to carry out analyses of stream waters in the areas both affected and unaffected by sealing operations. As these tests were made in connection with other laboratory operations, their results have had a definite

significance, both in themselves and in relation to those of routine examinations bearing on general sanitary conditions in the same streams.

The special studies above enumerated have been carried out for different reasons. The study of changes in stream acidity resulting from mine sealing were instituted in order to ascertain more definitely than could be determined by ordinary observational methods the effects of mine sealing in quantitative terms of stream improvement. This study, instituted late in 1940, was confined to a test area near Morgantown, W. Va., where the effects of complete and partial mine sealing, with an unsealed area as a control, could be observed over a period of several months with all other conditions, geological and meteorological, practically the same for each subdivision of the test area.

The study of substances causing tastes and odors in water supplies was undertaken in cooperation with the departments of health of Ohio, Pennsylvania and West Virginia, as presenting one of the more serious problems of industrial wastes pollution affecting water supplies in the upper section of the Ohio Basin. This study was centered in the lower Kanawha River and in the Mahoning-Beaver area.

The study of mud deposits was one of special interest as bearing on the extent and distribution of these deposits in pooled sections of the river and on the degree to which they are affected by organic solids originating in sewage and industrial wastes. The deoxygenating effect of sewage deposits, where prevalent in relatively large quantities, would tend to impose an added burden on the oxygen resources of the overlying stream.

The biological study of the effects of stream pollution on plankton and higher aquatic life was an essential part of the regular laboratory survey, as it dealt with an important phase of the problem untouched by the other laboratory observations. Probably the most important practical element in the biological phase of this problem has been the effects of pollution on fish life. This question, though studied by the U. S. Bureau of Fisheries in connection with its other investigations, had not been considered previously with specific reference to the

pollution of the Ohio River and its tributary streams. It had not been touched upon in any previous sanitary surveys of the Ohio River. Its importance in relation to the recreational use of streams in the Ohio Basin, as well as to the maintenance of desirable sanitary conditions in streams devoted to other uses, afforded ample justification for a thorough study of it in connection with this survey. As this study has been covered fully in a separate report by the Biologist of the Survey, it will not be dealt with in the present supplement.

Organization of Laboratory Operations

In accordance with a general plan of operations adopted in October, 1938, the Stream Pollution Investigations Station of the Public Health Service at Cincinnati was designated to undertake the necessary laboratory work incidental to the Ohio River Pollution Survey. The instructions issued in this connection included authorization for detailing necessary personnel to the work from the regular staff of the Station, for nominating additional personnel, and for obtaining all supplies and equipment necessary to carrying out the laboratory operations. An officer of the Cincinnati Station was detailed to organize and direct the laboratory work and other officers have acted as technical advisors from time to time.

The original plan of the Survey, as approved by the supervisory Ohio River Committee, provided for a three-year period of laboratory observations, covering approximately one-third of the entire basin each year and using the same personnel and equipment from year to year. The section to be covered during the first year, 1939, included the entire area draining into the Ohio River from the Kanawha to the Kentucky River, inclusive.

In order to carry out the laboratory operations, a staff of 30 technicians, office workers and field assistants was assembled early in 1939, trained at the Cincinnati Station and assigned to duties as rapidly as thorough training permitted. Meanwhile, equipment was purchased for a fixed base laboratory at the Cincinnati Station, which was made the headquarters for the work,

and a floating base laboratory was equipped on the quarter-boat "Kiski", loaned for the purpose by the Corps of Engineers, U. S. Army. Active laboratory work was started at the Cincinnati laboratory in February, 1939, while the assembly of personnel and equipment was in progress. Two mobile trailer laboratories were purchased and equipped for observations in the more distant areas of the drainage basin, not readily accessible from the base laboratories located on the main Ohio River. Two motor boats, loaned by the U. S. Bureau of Fisheries, were overhauled and outfitted for sample collection work on the main river.

After the first year of operations had been carried out according to the original plan, the Ohio River Committee met in February, 1940, and decided to have the entire survey completed during the year 1940, so far as practicable, thus compressing into one year the work originally planned for two years. This decision involved practically a two-fold intensification of laboratory operations, with added equipment and augmented personnel. The latter consisted of twenty-seven more workers added to the original staff, making a total personnel numbering fifty-seven. Additional equipment purchased in order to carry out this intensified plan included four more mobile laboratories and two new motorboats, together with a considerable amount of laboratory apparatus and supplies.

In the accompanying map (Figure 1) is shown a double-hatched area marking the territory covered by laboratory operations in 1939, aggregating some 60,000 square miles. The unhatched portion, totaling about 144,000 square miles, was the area covered by operations in 1940, including portions of the Tennessee and Cumberland Basins surveyed by the Tennessee Valley Authority and the Tennessee Department of Health respectively. This portion of the map also shows by arrows the general routes of mobile laboratory operations and the section covered by the Kiski laboratory.

In Table 1 is shown a time schedule, by months, of the routine laboratory operations carried out during the entire period of the survey. The operations during the year 1939, in the middle-third area of the Basin were

Figure-I

Areas covered by Laboratory Operations in 1939 and 1940

OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

shared by five different types of laboratory units, including those of the Scioto River Investigation, a separate project of the Public Health Service, and the Dayton Sewage Treatment Plant, which cooperated with the Survey in laboratory observations in the lower section of the Miami River. During this period, continuing observations by the Cincinnati and Kiski laboratories covered parts of eight tributary areas, in addition to the middle-third section of the main Ohio River from Point Pleasant to Dam 39. During the year 1940 and up to the end of March, 1941, the laboratory operations were carried out by the Kiski laboratory, along the upper section of the Ohio River, and by the six mobile trailer laboratories, in the outlying tributary areas and along the lower section of the main river. Operations in the upper and lower tributary areas in 1940 were not continuous during periods of several months, as was the case in 1939 for the middle-third area. This was due to the necessity of covering more areas by means of mobile laboratory units, which in some instances were obliged to work back and forth from one tributary area to another, in order to economize on time and travel distances.

Methods of Laboratory Operations

During the year 1939, laboratory operations along the middle third of the Ohio River were divided between the base laboratory at Cincinnati and the floating "Kiski" laboratory located at Dam 29, just above Ashland, Kentucky. During the year 1940, the upper section of the main Ohio River was covered from the Kiski laboratory at two locations, East Liverpool and Marietta, respectively. The lower section, extending from the Kentucky River to the mouth of the Ohio at Cairo, was covered by a mobile trailer laboratory with a motorboat for sample collecting in the main river. The other five trailer laboratories covered the entire outlying tributary areas except those within convenient access to the base laboratories located along the main river. Portions of the Cumberland and Tennessee river basins were omitted from the survey because they were being or recently had been covered by the Tennessee Health Department and the Tennessee Valley Authority, respectively.

TABLE 1 SCHEDULE OF ROUTINE LABORATORY OPERATIONS, BY MONTHS, 1939-41.

Watershed	1939												1940												1941			
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Allegheny																			T	T	T	T	T	T				
Monongahela																	T	T	T	T	T	T	T	T				
Beaver																		T	T	T		K	K	K	T			
Muskingum																T	KT	KT	KT	K	K				K	K	K	
Little Kanawha																	K	K	K	K	K				K	K	K	
Hocking										T	T					T	T	K	K	K	K				K			
Kanawha								K	K	K	K	KT	KT	KT	KT	KT	T	T								T		
Guyandot						K	K	K	K	KT	KT	K	K	K	KT	KT												
Big Sandy						K	K	K	K	K	KT	KT	K	K	K	K												
Scioto	S	S	S	S	S	S	SC	C	TC	TC	TC	C	C	C	C	C												
Little Miami	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C											
Licking		C	C	C	C	C	C	C	CT	CT	CT	CT	C	C	C													
Miami		C	C	C	C	CD	CD	CDT	CDT	CD	CD	CD	C	C	C	C												
Kentucky			C	C	C	C	C	C	CT	CT	CT	C		C	C	C			T			T			T			
Salt																			T	T		T				T		
Green																				T	T	T	T			T		
Wabash																			T	T	T	T	T			T		
Cumberland																				T	T	T	T		T	T	T	
Tennessee																					T	T	T		T	T	T	
Ohio-Pittsburgh-Dam 13																	T	T	T		T	K	K	K	K		T	
Ohio-Dam 14 to Dam 22 Incl.																	K	K	K	K	K				K	K	K	
Ohio-Pt.Pleasant-Dam 32						K	K	K	K	K	K	K	K	K	K	KT												
Ohio-Dam 33 to Dam 38 Incl.	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C											
Ohio-Below Dam 39 to Mouth																			T	T	T	T	T	T	T	T	T	

Symbols:
C - Cincinnati Laboratory K - Kiski T - Trailer laboratory unit S - Scioto River Investigation D - Dayton Sewage laboratory.

Sample Collections

Through the cooperation of the Corps of Engineers, arrangements were made for the regular collection of samples at the locks and dams along the upper and middle section of the main Ohio River. These collections were made by the lock personnel, using boats with outboard motors, in accordance with a schedule providing for two or three collections each week at each lock.* Samples were collected at three points on a cross-section located 1,000 to 1,500 feet upstream from the dam. Deep water sampling equipment was used, similar to that previously developed by the Public Health Service in other stream surveys. All samples were collected at mid-depth points in the stream cross-section. After being collected, the samples were transported by automobile without delay to the nearest base laboratory for analysis.

For the collection of samples from tributary points located within convenient travel distance from the base laboratories, regular personnel were employed by the survey. These sample collectors used their own automobiles for transportation and either highway bridges or boats as means of reaching the stream sampling points. On the tributary streams samples were collected generally at mid-points and mid-depths, using a deep or shallow water sampler, as needed. For reaching some points at the mouths of main tributaries and in the Ohio River between the locks and dams, motorboats were used, being operated by Survey personnel.

In Figures 2 to 7, inclusive, are shown illustrative views of the equipment used in collecting samples of the stream waters and bottom mud deposits.** Figure 2 gives two views of the deep water sampler, assembled and unassembled. The sampler is made of heavy cast bronze, with a rubber gasket sealed cover and weighted with lead in the bottom. In Figure 3 is a view of the sampler mounted on a bridge hoist, ready for action. Figure 4 pictures a surface or shallow stream sampler, mounted on a pole. In Figure 5 is shown a deep water mud deposit

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(*) For detailed instructions on the collection of these samples, see Appendix 1, Memorandum No. 1.

(**) For a detailed description of this equipment, see article on "Mechanical Aids for Stream Surveys," by C. T. Carnahan, Public Health Reports, Vol. 56, No. 16., Apr. 18, 1941, pp 815-821.

dredge of the clam-shell type, mounted on a hoist and operated by a hand-winch. This dredge can be operated in stiff materials such as clay, and will bring up about one-half cubic foot or more of mud. Figure 6 shows two views of a light-weight surface mud sampler, one being in an open position as lowered to the deposit and the other, in a closed position after collection of the mud sample. Both this and the clam-shell dredge were devised by Public Health Engineer C. T. Carnahan of the Public Health Service. In Figure 7 is pictured one of the motorboats at the time of collecting a sample of river water. This was one of the two older boats loaned by the U. S. Bureau of Fisheries.

In Figure 8 is an illustration of the floating laboratory Kiski loaned by the Corps of Engineers, the lower deck being used for laboratory work and the upper deck as an office and living quarters for the crew and unmarried men of the technical staff. The members of the staff quartered on the boat provided and maintained their own sleeping quarters and commissary. Every man in the staff was called upon to help with the mooring and navigation of the boat, as required, though three shipkeepers were employed especially for this purpose. A 24 hour watch was maintained by these men as a part of their regular duties. The Engineer in Charge of the laboratory also was responsible for the maintenance and navigation of the boat and its equipment.

Trailer Laboratories

The general method of operating the mobile laboratories was as follows: Before undertaking the survey of a given area, maps were prepared at the Cincinnati headquarters showing the sampling point locations for different stream areas and a central place in each area at which the mobile laboratory could be located for a period of two or three weeks while the particular area was being covered by stream examinations. Preliminary correspondence resulted in a tentative location for each stopping place of the mobile units. The travel routes for each unit were laid out for successive areas to be covered and an estimate made of the necessary time schedule of travel. As previously noted, a field engineer was sent in advance to complete detailed arrangements for each location and to survey the tentative sampling

Figure 2 - Deep water sampler, open and closed.

Figure 3 - Sampler hoist, mounted on a bridge.

Figure 4 - Shallow water sampler

Figure 5 - Clam-shell mud dredge sampler

Figure 6 - Surface mud sampler, open and closed.

Figure 7 - Collecting a river water sample from a motorboat.

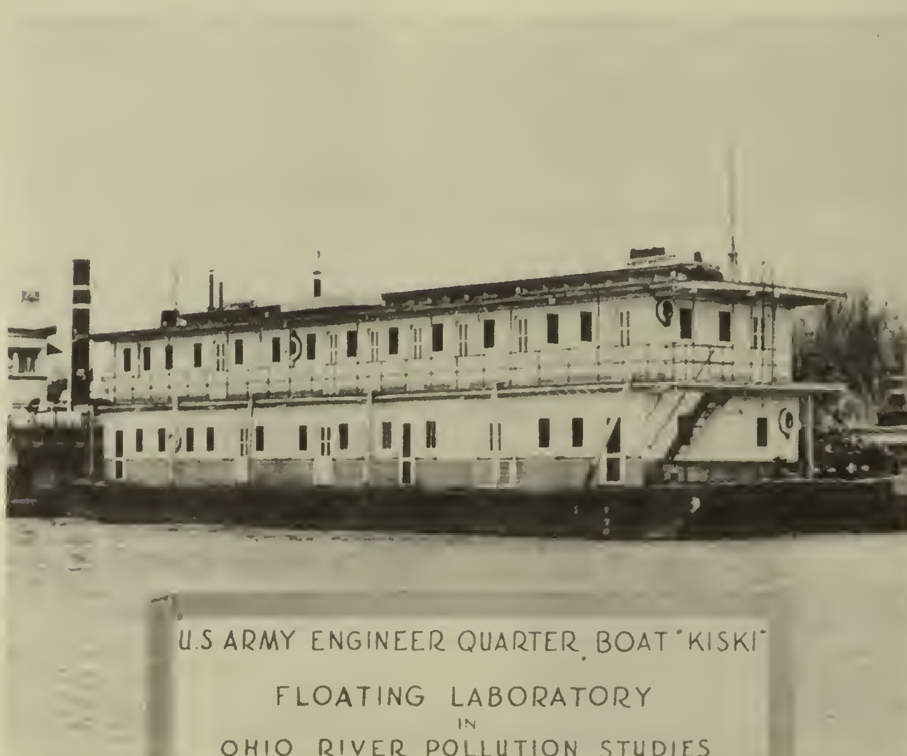

Figure 8.

points, relocating them where local conditions indicated this to be desirable. The field engineer then prepared a detailed map showing the exact location of each sampling point and the highway routes necessary to reach it from the central location. This information, together with any other pertinent data, was turned over to the chemist in charge of each mobile unit, which then proceeded with its work in each location with a minimum loss of time. In Figure 9 is a typical guide map showing the location of a sampling point.

Each mobile laboratory was manned by a crew of three men, consisting of a chemist in charge, a laboratory attendant and a chauffeur-sample collector. In the accompanying map (Figure 10) are shown the travel routes and central location points followed by each mobile unit during the campaigns of 1939 and 1940. In Figures 11 to 13, inclusive, are typical exterior and interior views of a trailer laboratory. An interior floor plan is shown in Figure 14*.

In practice, the mobile laboratories usually were located at local water works or sewage treatment plants, where continuous supplies of water and electric current were available. These supplies were connected directly to the laboratory through extension hose and cable, forming part of the trailer equipment. Supplies of chemicals and apparatus were maintained by shipments from the headquarters laboratory at Cincinnati.

Laboratory Determinations and Methods

Every possible effort was made in the laboratory work of the Survey to obtain comparable results in accordance with current standard methods of water examinations. Recognizing that with several laboratories in operation, small variations in procedure might tend

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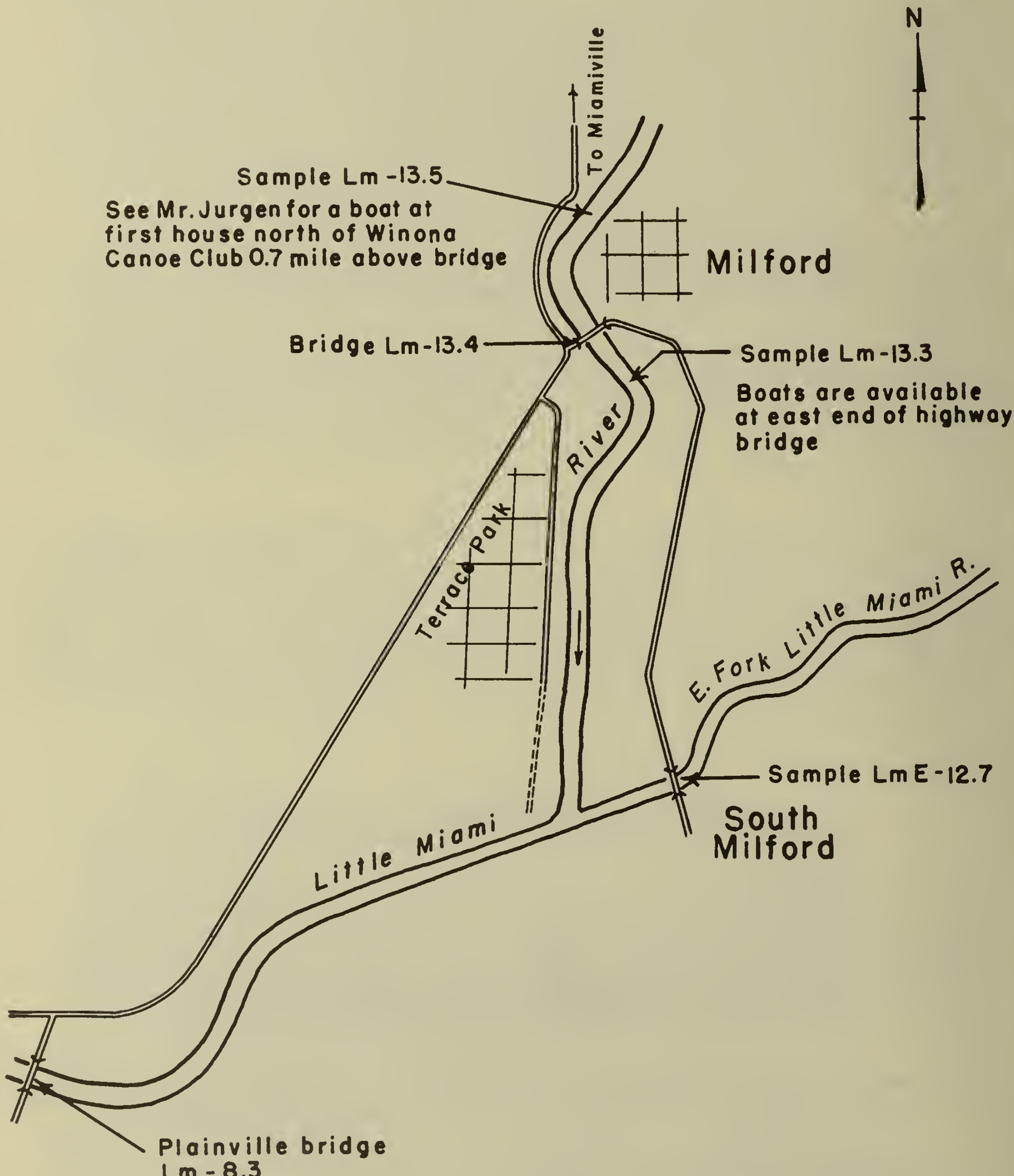
(*) For a detailed description of the trailer laboratories, see article on "Mobile Laboratory Units of the Ohio River Pollution Survey", by F. E. DeMartini. Public Health Reports, Vol. 56, No. 15, Apr. 11, 1941, pp 754-760 see Reprint No. 2259. Detailed specifications for these units are given in Appendix II of this supplement.

Figure-9

Typical Map of Sampling Point Locations



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1942

Fig.-10

OHIO RIVER BASIN

LOCATION OF LABORATORY
UNITS DURING PROGRESS OF THE
OHIO RIVER POLLUTION SURVEY 1939-1941

OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION

Fig.-10

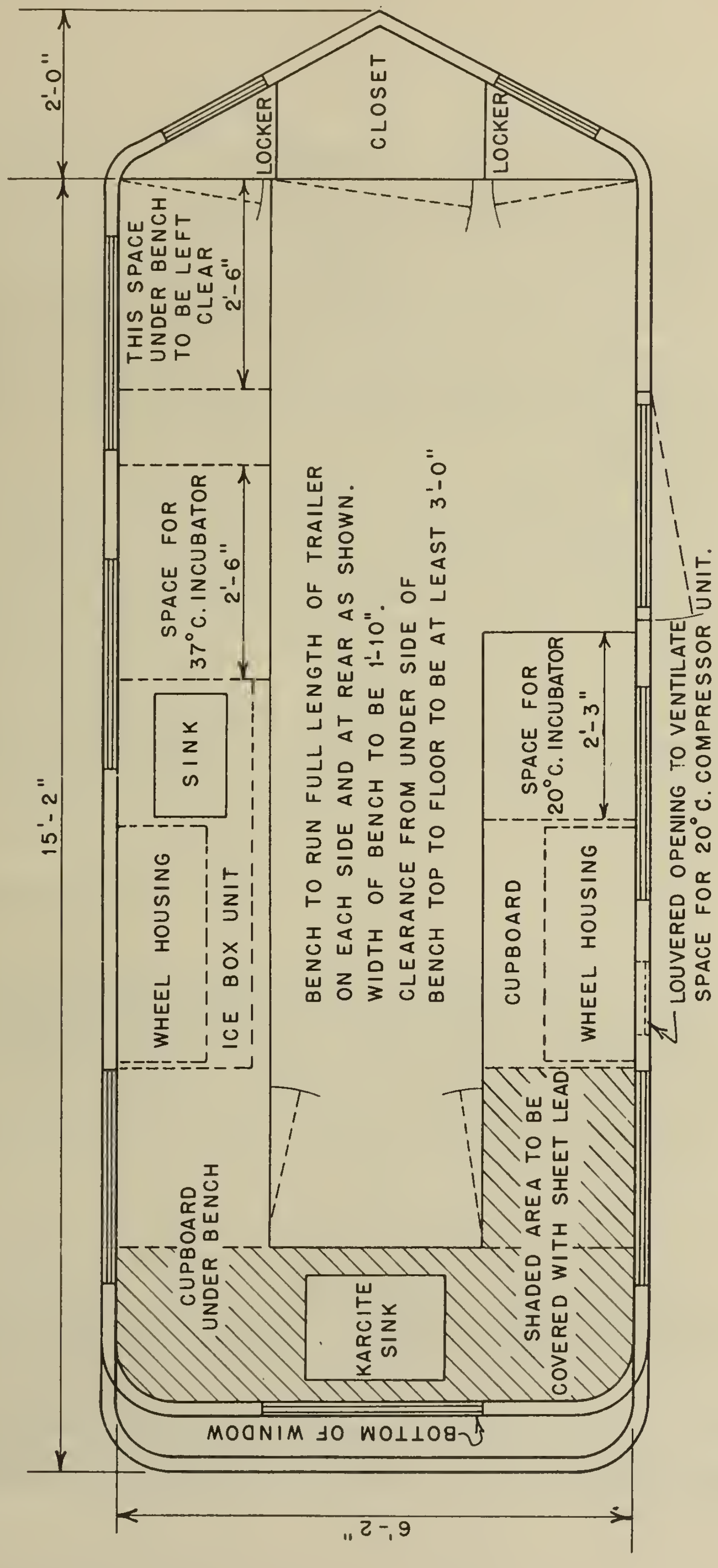
Figure 11 - Trailer laboratory, with towing car.

Figure 12 - Trailer laboratory in operation.

Figure 13 - Trailer laboratory, inside view.

Figure-14

Interior Plan of Trailer Laboratory



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1942

to vitiate the mutual comparability of the results, a systematic and thorough instruction in laboratory methods was given to each technician at the Cincinnati headquarters laboratory before his assignment to regular duty. This course of instruction usually occupied from four to six weeks. Throughout the progress of the field work, a qualified member of the laboratory staff was detailed to visit in turn each base and mobile laboratory in order to check analytical methods and results and to correct any inconsistencies.

In this connection, detailed instructions also were given to the chemists in charge of mobile laboratory units concerning the management of these units. In this connection reference is made to Appendix I, Memorandum No. 11, which contains information prepared especially for the mobile laboratory crews. In Memorandum No. 2 of the same Appendix is a general statement of the plan and objectives of the survey which was prepared for the guidance of all of the members of the laboratory staff.

The routine laboratory tests made on stream water samples were as follows:

A. Physical and chemical tests: (See Appendix I, Memorandum No. 4)

(1) Temperature; (2) turbidity; (3) pH value; (4) alkalinity; (5)* total and volatile suspended matter; (6) dissolved oxygen; and (7) 5-Day biochemical oxygen demand at 20° C.

B. Bacteriological tests: (See Appendix I, Memorandum No. 3)

(1)* 24-hour agar plate count at 37° C.; (2) coliform bacteria, "most probable numbers", by standard fermentation tube test at 37° C.; (3)* direct plate count of coliform bacteria on brilliant green lactose bile medium at 37° C.

(*) Discontinued as a routine test after the end of the year 1939.

The following brief notes may be inserted at this point to explain the significance of the various tests above enumerated.

A. Physical and Chemical Tests.

(1) Temperature

The temperature of stream waters governs their solubility for oxygen and hence the saturation level of dissolved oxygen in streams. This saturation level varies inversely with the stream temperature, being lower at higher temperatures and vice versa. Temperature also has a marked influence on rates of natural purification, which are increased at higher temperatures and diminished at lower temperatures.

(2) Turbidity

In stream waters, turbidity is measured in terms of parts per million (p.p.m.) or milligrams per liter, of a standard suspension of diatomaceous earth. It is an index of the density of silt, or other suspended matter, carried by a stream.

(3) pH value

The symbol "pH" denotes the logarithm of the reciprocal of the hydrogen ion concentration in a given water, this symbol being a universal one in chemistry. In general, the pH value indicates the relative acidity or alkalinity of a water, being lower with higher degrees of acidity. The normal value for neutral distilled water is 7.2, higher values indicating the presence of alkaline earth salts and lower values, the presence of acids or acid salts.

(4) Alkalinity

The alkalinity of a natural water represents its content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates and phosphates. It is measured by titration with a standard solution of a strong acid to certain standard datum points or hydrogen ion concentrations. In the present survey, standard sulphuric

acid has been used, with methyl orange as an indicator, showing a definite color change at a hydrogen ion concentration of 0.0001 (or pH 4.0).

(5) Total and volatile suspended matter

The total suspended matter content of a natural water is determined by filtering a sample of standard volume and weighing the dried residue. It represents the concentration of suspended matter in terms of dry solids. The volatile matter is determined by the loss of weight in the total dry solids after the application of heat under standard time and temperature conditions. It is a measure of the suspended organic matters present in the water.

(6) Dissolved oxygen

Although oxygen is only slightly soluble in water (about 9.2 p.p.m. at 20° C.), it can be measured accurately to less than 0.1 p.p.m. Dissolved oxygen is essential to the natural purification of stream waters and to the maintenance of fish and other aquatic life. In natural bodies of water, the dissolved oxygen is drawn upon to support biochemical oxidation of organic waste matters, but tends to be replenished by absorption from the atmosphere and the photosynthetic action of some water plants, including algae. A deficiency in the dissolved oxygen content of a polluted stream below the saturation level indicates the presence of polluting organic substances which are absorbing oxygen from the stream water. The degree of this deficiency is a measure of the deoxygenating effect of polluting matters and hence an index of the degree of pollution in a particular stream zone.

In an ideal situation in which a stream receives sewage or industrial waste at a single point and rapid admixture with the stream water takes place, the dissolved oxygen content tends to follow a typical "sag" curve on the basis of time and temperature, reaching a minimum point usually in one to three days time of flow below the source of pollution, depending on the temperature, oxygen demand and rate of reaeration. The specific rate of atmospheric reaeration is influenced slightly by stream temperature but largely by the turbulence of flow, which varies widely in different streams, or sections of the same stream. The minimum point of the "oxygen sag" curve

is perhaps its most important parameter from an observational standpoint, as it marks the most unfavorable condition which may affect fish and other aquatic life, or the possibility of occurrence of "nuisance" conditions in a stream. Desirable limiting requirements in this oxygen minimum point are discussed in the main report of the survey.*

(7) Five-day biochemical oxygen demand (B.O.D.)

The standard test for biochemical oxygen demand (B.O.D.) involves the incubation of sealed samples of a stream water for 5 days at 20° C. and the measurement of the loss of dissolved oxygen by the sample during the period of incubation. This loss represents the 5-day biochemical oxygen demand of the sample. When diluted initially with B.O.D.-free water, the oxygen demand of the original sample is found by applying the dilution ratio to the measured loss of dissolved oxygen.

The B.O.D. as thus determined is a measure of the amount of dissolved oxygen which may be expected to be absorbed from a stream water in 5 days at 20° C. in order to support the biochemical oxidation of the organic pollutants carried in the stream at the time of observation. Organic matters originating in sewage have been found experimentally to be oxidized in this manner according to a logarithmic time-function curve, which varies in its rate of progression with the water temperature, the rate being faster at higher temperatures. Hence it is possible to estimate the amount of oxygen demand satisfied in any time and at any temperature, having observed it at a standard time and temperature.

B. Bacteriological Tests.

(1) 24-hour plate count at 37° C.

This determination consists in mixing a measured portion of the water sample with a melted sterile culture medium containing agar, spreading the mixture in a sterile glass petri dish, allowing it to become hardened to a

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(*) See pages 32-35, Introductory and General Sections, Report to Ohio River Committee.

stiff, jelly-like consistency and incubating the hardened culture for 24 hours at 37° C. At the end of this period, visible colonies formed from individual or clumped bacterial cells are counted and their number is taken as an index of the density of bacteria in the original sample. As the species of water bacteria appearing on these plate cultures are numerous and varied, the bacterial count obtained in this manner is only roughly indicative of pollution. When considered in conjunction with the determination of numbers of coliform bacteria, the plate count is of value, both as an indicator of pollution and as a rough measure of natural purification.

(2) Determination of coliform bacteria

This determination affords the most delicate and specific test for pollution of stream waters by sewage, as it shows the approximate density of a group of bacteria which are always present in large numbers in sewage and are relatively few in numbers in other stream pollutants. Coliform bacteria are normal inhabitants of the intestines of warm-blooded animals and are discharged in very large numbers in human feces, which constitute the principal source of these bacteria in sewage.

The test for coliform bacteria is made by adding measured portions of a water sample to a lactose broth liquid culture medium in tubes especially designed for showing gaseous fermentation of the lactose. After 24 to 48 hours of incubation at 37° C., tubes showing the presence of gas are considered as giving presumptive evidence of the presence of coliform bacteria, which are lactose fermenters. After the necessary confirmatory tests, the result is recorded as positive or negative. The "most probable number" (M.P.N.) of coliform bacteria is determined from the numbers of tubes giving a positive result with different volumes or dilutions of the original sample. The principle underlying this method of enumeration is based on the theory of probability, a given result having a definite maximum probability that a definite number of coliform bacteria per unit of volume (i.e. a milliliter or 100 milliliters) is present in the sample tested. Although this method is subject to a considerable error in single determinations, it probably affords the most logical and relatively precise one available for determining small densities of coliform bacteria from fermentation tests.

(3) Direct plate enumeration of coliform bacteria

This method, originally developed in its present form by Noble and Tonney, utilizes the plate-count procedure described above under B-(1), but depends on the use of a culture medium which is selective for bacteria of the coliform group. Experience with its application to a large number of water examinations in the present survey has indicated that it gives average results which agree fairly well with those of the fermentation test, though individual results may show considerable divergence. The relative precision of the direct count seems to vary to some extent with the density of coliform bacteria present in the sample and also with the number of countable colonies on the plates. A certain degree of skill, resulting from experience, is necessary for the identification of colonies on the plates which are typical of coliform bacteria. The culture medium is only partly selective as it permits the growth of a limited range of non-coliform species.

Additional tests of a special nature, made only on certain samples, have included nitrite, nitrate, acidity to phenolphthalein (hot and cold), and total hardness. In some cases routine tests for turbidity and alkalinity have been limited to samples from certain key points. Biological tests have been carried out as indicated in the section of this report devoted to the biological survey work. (Appendix 1, Memorandum No. 8)

From time to time it has been desirable to examine certain types of industrial wastes concerning which little has been known of their composition and more especially as to their suspended and volatile matter content and biochemical oxygen demand. These tests have been made as required, both at the base and at the mobile laboratories.

During the year 1940 considerable numbers of samples of bottom mud deposits collected from the Ohio River were examined at the Cincinnati base laboratory. The tests made on these samples included biochemical oxygen demand after 2, 4, 6, 8 and 10 days, total and volatile matter, moisture content, and amounts of potassium permanganate and bichromate consumed under standard time and temperature conditions.

In connection with the mobile laboratory operations, a regular practice was made of examining bacteriologically the more important public water supplies of communities visited by these laboratories. At the Kiski laboratory and in connection with the special study of taste and odor difficulties in water supplies along the Mahoning and Beaver Rivers, numerous routine tests for phenol content were made on stream waters suspected of being involved in these difficulties.

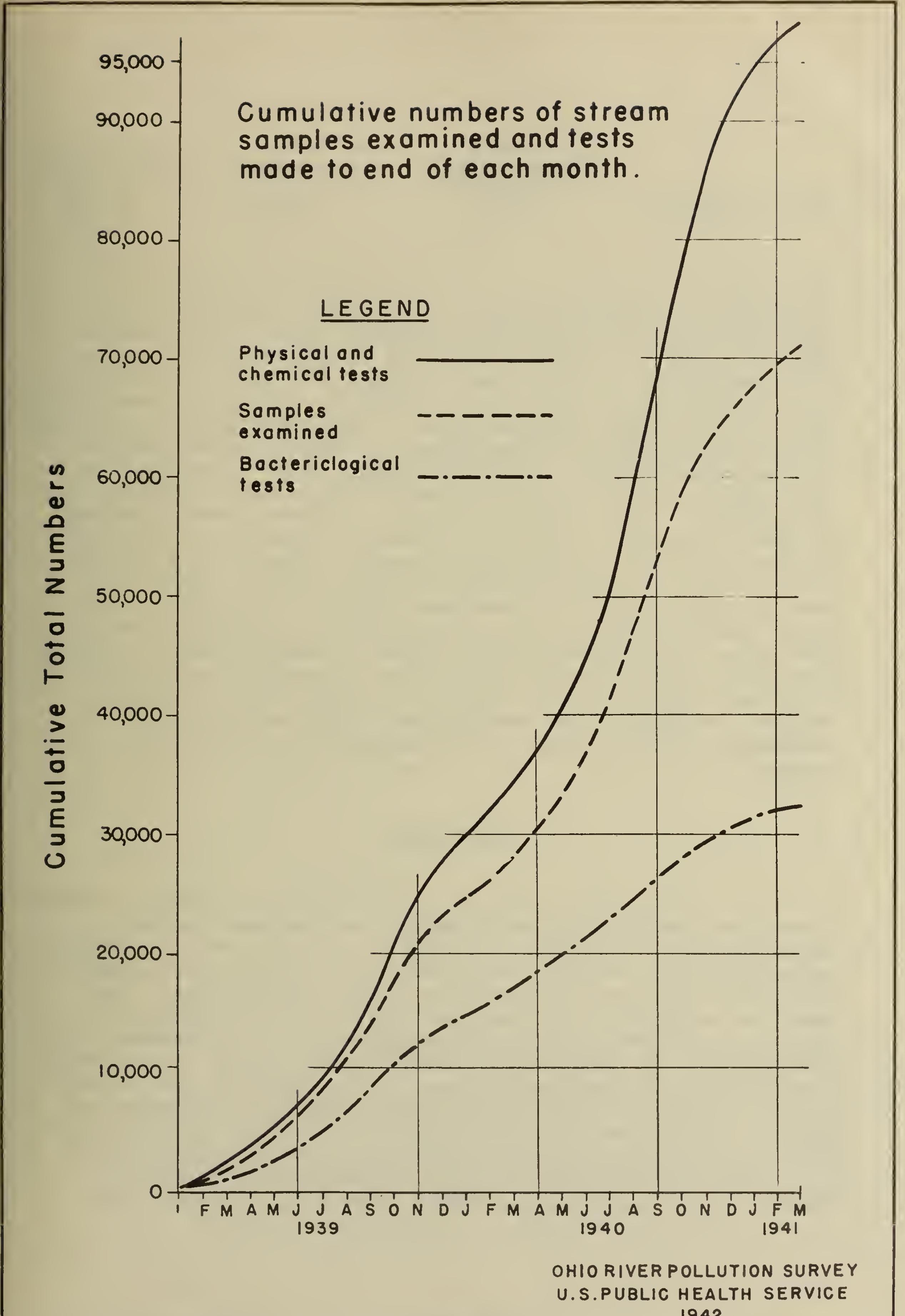
Summary of Routine Laboratory Operations

Up to the end of March, 1941, when routine laboratory operations were terminated, a total number of 71,124 water samples had been collected and examined in connection with the Survey, exclusive of samples examined biologically. The total number of examinations made on these samples was 131,132, of which 98,554 were physical and chemical tests and 32,578 were bacteriological examinations. The average number of samples examined during the 26 months of the laboratory operations was about 2640 per month, with a maximum number of 6570 in August, 1940, when operations were at their highest intensity. The number of laboratory tests averaged about 5,000 per month for the entire period of the Survey and reached a maximum number of 11,420 in August, 1940.

In Figure 15 are shown graphically the total number of samples examined and tests made up to the end of each successive month, beginning with January, 1939, when a few samples were collected from the Ohio River at Cincinnati. The effect of winter curtailment of the stream examinations, owing to adverse weather conditions, is apparent in the trend of the curves during the December-February period of 1939-40. Part of the lag in the upward trend of the curves shown for this period was due, however, to the reorganization incidental to carrying out the accelerated plan of operations adopted in February, 1940. The lag near the end of the survey period indicates the effect of curtailing operations gradually, beginning in October, 1940.

On the basis of records maintained throughout the progress of the survey, the average amount of work performed by one mobile laboratory unit per month was as follows:*

(*) Figures taken from article by F. E. DeMartini, previously cited.


Cumulative numbers of stream samples examined and tests made to end of each month.
LEGEND
Physical and chemical tests
Samples examined
Bactericlogical tests
Cumulative Total Numbers
95,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
I F M A M J J A S O N D J F M A M J J A S O N D J F M
1939
1940
1941
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

	Mobile Laboratories	Kiski Laboratory	Cincinnati Laboratory
Cost per sample	$2.78	$2.26	$1.79
" " test	1.22	1.13	1.09

The somewhat higher unit cost of operating the mobile laboratories was due mainly to the conditions of their operation, which necessitated moving them from place to place about every two weeks, thus entailing some degree of interruption in the work, whereas the base laboratories were operated on a continuous schedule, with no interruptions due to extraneous circumstances. Another important element in the higher cost of operating the mobile laboratories was the added expense of maintaining their personnel in the field, which included an extra per diem allowance for subsistence. The base laboratory personnel were located at fixed stations and did not receive such an allowance. In the absence of this added item of expense, the mobile laboratories would have shown a considerably lower unit cost of operation, because less capital and upkeep expense was involved in providing and maintaining them. This type of laboratory was found to possess many practical advantages over those of fixed location in covering a large and varied stream area. It was in some respects the most valuable new device for facilitating stream pollution surveys which was developed in the present survey.

Personnel

The laboratory operations of the Survey were performed under the administrative direction of Senior Sanitary Engineer J. K. Hoskins, in charge of the Stream Pollution Investigations Station at Cincinnati, who was succeeded in July, 1940, by Medical Director H. E. Hasseltine. The work was organized and carried out under the technical direction of Senior Sanitary Engineer H. W. Streeter, with Biologist F. J. Brinley in immediate charge of biological studies, Public Health Engineer C. T. Carnahan and Passed Assistant Sanitary Engineer F. E. DeMartini in charge of mobile field laboratories, and Public Health Engineer S. G. Monroe in charge of the floating base laboratory "Kiski". Principal Bacteriologist C. T. Butterfield, Principal Chemist C. C. Ruchhoft, Special Expert W. C. Purdy and

Senior Biologist J. B. Lackey, all from the regular staff of the Cincinnati station, cooperated actively in training the laboratory personnel, preparing instruction memoranda on laboratory methods and in acting as technical advisors in various phases of the work. Passed Assistant Sanitary Engineer (R) C. L. Chapman was in charge of the special acid stream work based at Morgantown, W. Va. The six mobile laboratories were under the immediate charge of Junior Chemists Stuart Cohen, Stephen Megregian, F. W. Middleton, J. I. Norris, O. G. Pettijohn and R. A. Snider. The laboratory work at the Kiski laboratory was performed by Assistant Chemist W. W. Walker and Bacteriologist B. S. Levine, and at the Cincinnati laboratory, by Assistant Chemist M. B. Ettinger and Junior Bacteriologist C. W. Chambers.

Acknowledgements

The laboratory work of the Survey was carried out with the active collaboration and assistance of several agencies which were most helpful in reinforcing the work of the regular staff. In the biological work, active collaboration was furnished by the laboratory of Interior Fisheries Investigations, U. S. Bureau of Fisheries, under the direction of Dr. M. M. Ellis, in examining numerous fish specimens as to their physiological condition and preparing a report of this work which is included as appendix to the general report of the biological investigations (See Supplement F, to the main report of the Survey). Cooperation in the biological work on fish life also was given by the Ohio Division of Conservation through Messrs. E. L. Wickliff and M. B. Trautman of that staff. The laboratory of the Dayton, Ohio sewage treatment plant, under the direction of Mr. M. W. Tatlock, carried out systematic examinations of stream waters in that vicinity as a direct contribution to the work of the Survey. The laboratories of the Tennessee Valley Authority and the Tennessee Department of Health made available the results of their extensive stream analyses in the Tennessee and Cumberland river basins, respectively. To all of these agencies and individuals grateful acknowledgement is due for their generous cooperation, which greatly facilitated the work of the survey and made possible certain economies in the scope of operations. Acknowledgement also is due to the various municipal officials, too numerous to mention

here, who assisted in providing location places for the trailer laboratories during their field operations, and to the State Sanitary Engineering Divisions which facilitated these arrangements. Finally, special acknowledgement should be made of the courteous assistance furnished by the offices of the Ohio River Division and of the District Engineers, Corps of Engineers of the U. S. Army, in arranging for the collection of river water samples at the navigation dams in the Ohio River and for the provision of various services and material supplies in connection with the operations.

A P P E N D I X   I

LABORATORY MEMORANDA

LABORATORY MEMORANDA

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Memorandum No. 1

December 15, 1938.

Collection of River Water Samples at U. S. Locks & Dams

Memorandum No. 1

December 15, 1938.

COLLECTION OF RIVER WATER SAMPLES AT U. S. LOCKS & DAMS

The following instructions have been prepared for the use of U.S. Engineer Corps personnel who may be assigned to the regular collection of river water samples at the Ohio River locks and dams and at the mouths of certain tributaries.

Sampling Equipment

The regular sampling equipment (sampler will consist of a bronze subsurface collecting vessel, fitted with a rope for lowering and raising the vessel and a heavy cord for operating the release cock. The hoisting rope will be marked at 5-foot intervals with colored twine. It is assumed that the collector will be provided with a skiff and out-board motor for use in collecting the samples.

The sampler is fitted with a cover, gasket and thumb-screw lugs for tightening the cover in place. A raised platform inside the sampler is provided with clips for holding three bottles. Two of these bottles are identical in shape and size, being intended for collecting duplicate samples for dissolved oxygen and biochemical oxygen demand tests. The third bottle (sterilized) is for the bacterial sample. In the cover of the sampler are tubes located so that they may be extended down into the three bottles when the cover is in place. One of these is a sterilized glass tube for the bacterial sample bottle. This tube will be changed for each collection. When the cover is locked in place, the tubes will project down into the bottles through their open mouths, the stoppers being removed when placing the bottles into the clips. A supply of bottles, with carrying cases, and glass tubes will be furnished the collector in advance.

Location of Sample Collection Points

Pending the more exact location of sampling points in the river and establishment of ranges for locating these points, samples will be collected at three points on a cross-sectional line extending across the channel about 500 feet upstream from each dam and in a direction parallel to the dam. One of the three points will be located approximately mid-way across the stream and the other two at points located approximately mid-way

between this center point and the shore in each direction. An effort will be made to obtain each sample at about mid-depth in the stream; that is, at a point about mid-way between the surface of the water and the bottom of the channel.

As soon as possible after the regular collection of samples has been started, U. S. Public Health Service engineers will locate permanent sampling cross-sections above and below each dam and will establish on each cross-section convenient range lines whereby the collector will be able to locate himself readily on each point. At the same time soundings will be made to establish the river depth at each point corresponding to pool stage or to some other known stage of the river and the corrected depth at other stages can then be determined by adding or subtracting 1/2 the number of feet which a given river stage is above or below the reference stage (i.e. pool or otherwise). Temporarily, the depth at each point can be established roughly by sounding with the collecting vessel, or with a sounding line, and then bringing the vessel to about one-half this depth.

Method of Collecting Samples

Before starting the collection each set of three sample bottles will be marked as "R", "C", or "L", denoting respectively the right, center and left points along the cross-section, facing downstream. In reaching the first point, whether it be the right (R) or left (L), the three bottles thus designated will be placed in the clips in the sampler with their stoppers removed (and remaining tied to the necks of the two identical bottles). The bacterial bottle will be wrapped in paper as delivered to the collector and will be sterilized before delivery, as it is intended for collecting a sample for bacteriological examination. The stopper of this bottle will be covered with tin-foil, which should not be removed in taking out the stopper. In handling this bottle and its stopper, the greatest care should be taken by the collector not to touch with hisfingers or anything else the inside of the bottle neck or the corresponding outer face of the groundglass stopper, or to lay the stopper down so that this face comes in contact with any surface. The object of this precaution is to prevent any contamination of the sample bottle from an outside source during collection of the sample.

The stopper should be handled with the tin-foil cover in place, so as to facilitate protecting it from contamination.

In inserting the sterilized glass tube for this bottle into the cover of the sampler, similar precaution should be taken not to allow the fingers to come into contact with the tube. By removing only a part of the wrapper from the tube, the bare end can be inserted in the cover by holding the covered end in the fingers.

After the bottles have been placed in the clips and the glass tube inserted in the cover, the cover is then placed on the sampler with the tubes projecting into the bottles, the thumb-screw lugs tightened into place and the air-release cock closed, with the handle turned to a horizontal position. The sampler is then lowered to mid-depth and the air-release cock opened by pulling the auxiliary cord. Water then will flow into the sampler until the air vent is trapped by the short tube. When the flow is stopped, the two duplicate bottles should be completely full and the third (bacterial) bottle, 1/2 to 3/4 full. During the filling operation, displaced air from inside the sampler will escape and appear at the surface of the river as bubbles. As soon as this air bubbling ceases, the vessel is ready to draw up to the surface and be lifted into the boat (it should be kept in a vertical position so far as possible while lifting it into the boat).

After removing the cover, the single bacterial sample bottle is removed first and its contents brought down, if necessary, to a level of about 3/4 full. The stopper is inserted with the same precautions against contamination by the fingers as above noted. This sample is then wrapped in its paper, with the tin-foil cover in place, and placed vertically in the carrying case. The two duplicate bottles are then removed, completely full, and their stoppers inserted so as not to allow any air to be trapped under them in the neck of the bottle. If water should be spilled from these bottles while removing them from the sampling vessel, they should be filled to the top with water drawn from the sampler with a glass pipette, before inserting the stoppers. These bottles, with their stoppers tightly inserted, will then be placed in the carrying case and the collector will proceed to the next sampling point, where the same operations as above described will be repeated.

Transporation of Samples to Laboratory

As a rule, the samples after collection will be taken by the collector to a designated point near the dam and there picked up by the U. S. Public Health Service collector, who will trans-

port them in his automobile to the laboratory. As the automobile transportation route will follow the right (Ohio-Indiana) bank of the river, arrangements will be necessary for delivering the samples to convenient points along that side. As soon as the automobile transportation has become established the collection of the samples from the river can be timed so as to involve a minimum of delay between the time of collection and the time of being taken up for transportation to the laboratory. Ordinarily, the working schedule will provide for the collection of a set of samples once each working day, or every other day, at some time between 3:30 A.M. and 9:00 A.M., depending on the distance of a particular dam from the laboratory and its position on the automobile transporation route. After this time has been established, it will be subject to little if any variation from day to day. During the warmer season, the samples after collection will be placed and kept in iced containers (to be provided by the laboratory) from the time of collection to the time of reaching the laboratory. This precaution is necessary in order to prevent multiplication of bacteria in the samples, with corresponding changes in their numbers, during transportation to the laboratory.

When stopping at each dam for the samples, the U. S. Public Health Service collector will leave a complete set of sample bottles with containers for the next collection. As a rule, an extra set of bottles will be kept at the dam for use when for any reason a set may not be delivered in time for the next collection. Each sample collector will be provided with a complete set of river sampling equipment which he will keep in a convenient place at the dam.

Special Samples

Occasionally, in order to meet the needs of the laboratory work, it will be necessary to request an extra sample of river water for transportation to the laboratory. Samples of this nature usually can be supplied from the surplus water in the sampler, using extra glass containers which will be furnished by the laboratory.

At certain dams, it will be necessary occasionally to request the collection of two sets of samples at one time, one being collected above the dam, as usual, and the other at least one-half mile below the dam (so as to remove the effect of any entrained air). Where the mouths of important tributaries are located near dams, regular collection of a single mid-point

sample from these tributary mouths may be requested, in addition to the set of samples from the main stream.

At some dams, notably Nos. 27, 29, 31, 37 and 38, a study will be undertaken of the nature of sludge deposits preceding and during periods of low water, when the effects of sedimentation will be most apparent. In this connection, it may be necessary to request the occasional collection of mud samples from the river bottom, using special equipment which will be provided by the laboratory. This will not entail any material increase in the time required for the collector's services, as collection of these samples can be made at the same time as that of the regular river water samples. It will involve no difficulties other than the occasional handling of the mud collection equipment.

APPENDIX - MEMORANDUM NO. 1

DETAILED INSTRUCTIONS TO SAMPLE COLLECTORS.

1. For collecting one complete set of samples of river water on a cross-section of the river, the following equipment will be provided to each collector:

(a) One deep-water sampler with lid, gasket, inside platform with clips, hoisting rope marked at 5-foot intervals and air-release valve with separate operating cord.

(b) Nine (9) bottles, of which six (6) are narrow-mouth, unwrapped, and three (3) are wide-mouth, wrapped (sterilized).

(c) An extra supply of bottles in case of breakage; also any extra bottles for special samples as required.

(d) Sterilized glass tubes in wrappers.

(e) A water temperature thermometer, mounted in a nonbreakage rod.

(f) A glass pipette and funnel.

(g) Carrying case for sample bottles and samples.

2. For the ordinary collection, a set of three (3) bottles will be collected at each one of the three (3) points on a river cross-section. For convenience, these three points will be designated by the letters (R), (C) and (L), denoting respectively the <u>right</u>, <u>center</u> and <u>left</u> points on the section, facing downstream. Each set of three bottles will consist of two narrow-mouth bottles (duplicates) and one wide-mouth bottle. Each set should be marked with its proper letter corresponding to the point of collection.

3. Locations of (R), (C) and (L) points will be furnished each collector in advance, mainly by means of shore ranges whereby he may locate himself on a given point in a boat under any river condition. Pending more exact location of these ranges, samples will be collected on a cross-section located

about 500 to 1000 feet above each dam, the (C) point being about halfway across the channel and the (R) and (L) points midway between the (C) point and the shore in either direction. Samples at each point will be collected at approximately mid-depth. Temporary ranges for these cross-sections will be established for the collectors, using two prominent landmarks, one on each side of the river, lined approximately at a right angle to the direction of the flow.

4. Before proceeding to the first collection point, the collector should place a set of three bottles in the sampler clips and insert a fresh sterilized glass tube into the hole provided on the under side of the sampler cover. Before placing the bottles the stoppers should be removed, those in the duplicate narrow-mouth bottles being left tied to the bottle neck and the stopper of the wide-mouth bottle being carefully removed with the tinfoil in place and inverted resting on its top at some convenient place in the boat.

Caution: In handling the wrapped wide-mouth bottle, do not allow the fingers to touch the inside of the bottle or its neck, or the ground face of the stopper. Save the wrapper for wrapping the sample after collection. In inserting the glass tube, do not allow the fingers to touch the tube itself. Handle one end with the wrapper in place,inserting the bare end.

5. With the bottles in place, the cover is then set on the sampler, with the two metal tubes projecting down into the narrow-mouth bottles and the glass tube into the wide-mouth bottle. Tighten the cover securely by means of the six thumb-screw lugs, with the gasket in place, so as to make a tight joint. The air-release valve should be closed, with its handle in a horizontal position.

6. The sampler is next lowered over the side of the boat into the river, being careful not to allow the air valve cord to become fouled with the hoisting rope. Using the 5-foot markers, the sampler is lowered to about mid-depth and while held in this position the air-valve cord is pulled smartly, so as to open the valve. As soon as this valve is open, water will flow into the sampler through the tubes and fill the bottles by several displacements, the air escaping through the air-valve and appearing as bubbles at the surface. As soon as these bubbles have stopped coming up to the surface, the sampler may then be hoisted back into the boat.

7. With the filled sampler in the boat remove the cover and place the thermometer in the water in the vessel, leaving it there for a later reading. Next, take out the wide-mouth

bottle, which should be about three-quarters full, insert the stopper carefully and restore the wrapper, being sure that it is properly marked with the letter designating the point and the number representing the location of the cross-section (this number will be furnished to the collector). Then remove the two narrow-mouth bottles, which should be completely full, and insert their stoppers so that no bubbles of air will be left in the bottle under the stopper. If the bottle is not completely full, draw a little water from the sampler vessel with the pipette and fill it in this way. Then read and record the temperature of the water as shown by the thermometer.

8. From the surplus river water left in the collector, remove enough to make up any special sample required and pour the rest overboard. A glass funnel will be furnished for use in pouring water from the sampler into an extra bottle if required.

9. Now proceed to the next two points and repeat operations (4), (5), (6), (7) and (8) at each point.

10. After each collection, place the samples in the carrying case, being sure that they are marked properly. Place the discarded glass tubes in the case and secure the cover of the case ready for transportation to the designated point on the shore.

11. After finishing the day's collection the sampler should be flushed out with clean water, the metal tubes and cover wiped clean and the rope and cord coiled neatly, ready for the next collection. The sampler and other equipment should be stored at a suitable place near the boat mooring. Directions will be given each collector as to where the carrying case containing the samples should be delivered after collection.

12. During the warm season, provision may be necessary for packing the samples in an iced container for transportation to the laboratory. These arrangements will depend on circumstances and on the availability of a small amount of ice locally. The iced containers will be furnished from the laboratory, when their use is necessary.

13. In collecting samples from tributaries, where required, a single point in the middle of the stream will be used, rather than three points as in the main river. Samples will be collected at mid-depth in tributaries as in the main stream.

Memorandum No. 2

December 29, 1938

Plan And Objectives of Laboratory Survey

Memorandum No. 2

December 29, 1938.

PLAN AND OBJECTIVES OF LABORATORY SURVEY

This memorandum has been prepared especially for the information of new personnel who have not been connected with previous work of the U. S. Public Health Service and have not been acquainted with the history, plan and objectives of the present survey of pollution of the Ohio River and its tributaries. It is hoped that through this medium those who will be actively engaged in the work, and especially in its laboratory side, will be enabled to gain a better perspective of the work as a whole and of the respective parts which they will play in it. It is only through such an understanding that individual effort may be intelligently directed to the particular work in hand and that a sense of pride and "esprit de corps" may be developed among those who will be collaborating in the very considerable task that lies ahead.

Historical Background of Present Survey

In the year 1912, an Act of Congress extended the functions of the Public Health Service and authorized investigations of "the diseases of man and conditions influencing the propagation and spread thereof, including sanitation and sewage and the pollution, either directly or indirectly of the navigable streams and lakes of the United States." In 1913 a special appropriation, continued annually since that year, was made for carrying out these provisions, including investigations of stream pollution. In the summer of 1913 work was begun on a study of the pollution and natural purification of the Ohio River, which was selected as a typical large inland stream receiving sewage, mostly untreated, and also used very largely as a source of public water supplies. This study was continued until the end of 1916.

At the time of this study, little was definitely known concerning certain fundamental quantitative relationships which are involved in the pollution and self-purification of rivers. The main objective of the study was to obtain some basic observations bearing on those relationships, such as the ratios of measurable sewage pollution to numbers of contributing population, the polluting effects of certain industrial wastes in terms of quantities of manufactured products and of equivalent sewage-contributing populations, and the various effects of time, temperature, pollution density, etc. on observable rates of

natural purification of sewage-polluted streams. Incidentally, a fairly comprehensive general picture was obtained of the status of pollution of the Ohio River proper in zones extending below certain major centers of pollution, such as Pittsburgh, Wheeling, Cincinnati and Louisville, and also of the more important tributaries at their points of entry into the Ohio. The observations did not extend to all sections of the Ohio River or to any of its tributary streams except at their mouths.

Interrupted by the World War, stream pollution activities of the Public Health Service were resumed in 1921 with a study of the Illinois River, followed by surveys in the upper Mississippi, the lower end of Lake Michigan and, in 1930-31, a resurvey of that portion of the Ohio extending from above Cincinnati to below Louisville. Although these several investigations indicated conditions of pollution in the waterways concerned, they were primarily research projects designed to throw further light on the more basic problems of river sanitation. These field studies have been supplemented by basic research work at the Cincinnati laboratory dealing with certain problems of water and sewage purification closely allied with those of stream pollution. In this category have been studies of the efficiency and limitations of water purification and of the mechanism of sewage oxidation by activated sludge.

The Present Survey

The present survey has resulted from the River and Harbor Act of August, 1937, Section 5 of which provides that the Secretary of War is authorized and directed "to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited, directly or indirectly, therein and the sources and extent of such deposits and with a view to determining the most feasible method of correcting and eliminating the pollution of these streams." It is also provided in the Act that the survey shall include comprehensive investigations of the various problems relating to stream pollution and its prevention and abatement; that cooperation and assistance of the Public Health Service may be secured, that a report shall be made to Congress with recommendations for remedial legislation, and that the expenses of the surveys shall be paid from current appropriations for rivers and harbors work.

Shortly after passage of this Act, a request for active collaboration in the survey was received and accepted by the Public Health Service. As the result of preliminary conferences it was agreed that the Public Health Service would carry out the following parts of the study: (1) necessary laboratory studies, chemical and biological; (2) collection and study of factual data relative to pollution; (3) determination of the character of water in the main stream and its tributaries; (4) determination of the extent of treatment of polluting material required and (5) all other investigations necessary to determine existing conditions and, as far as possible, future conditions which may have bearing on the pollution problem. A lump-sum allotment of funds has been made to the Public Health Service by the War Department for carrying out this general program of work, a portion being made available for the current fiscal year.

Projected Work for the Current Year

For the current year, the proposed work will consist of:

1. Laboratory studies of the Ohio River proper between the mouth of the Kanawha and the mouth of the Kentucky River to determine existing conditions of pollution.

2. A study of the extent and effect of organic sludge deposits in the existing pools and especially in those formed by permanent dams.

3. Laboratory study of streams in the coal mining area to determine the amount of acid and acid salts carried by the river.

4. Surveys of the tributary streams entering the Ohio River between the Kanawha and Kentucky Rivers to determine the extent of pollution and remedial measures necessary.

5. Continuing surveys of the pollution of the Tennessee and Cumberland Rivers now under way, in cooperation with the Tennessee Valley Authority and the State Department of Health of Tennessee.

SURVEYS OF SOURCES OF POLLUTION

The work of the Survey has divided itself quite naturally into two main sections, one consisting of field surveys of sources of pollution and the other, laboratory surveys of the streams. The first section of the work, which is being organized as a separate project under Mr. Crohurst and Mr. Tisdale, will involve the systematic collection of data from state departments of health and other agencies bearing on sewered populations along the various streams, the amounts and kinds of wastes discharged by industries, the extent of sewage and industrial wastes treatment and allied matters. This survey also will disclose the locations of stream zones in which conditions of pollution are bad or unsatisfactory, thus pointing toward areas which may require some degree of laboratory study. It also will be concerned with the collection of basic data for later engineering studies of the interception and treatment of sewage from various areas of pollution.

HYDROMETRIC DATA

An essential part of the basic data for a survey of river pollution consists of detailed information bearing on the volume of flow of a main stream and its tributaries, not only throughout the period of the survey, but also during a term of previous years, in order to establish the relative normality of various flows encountered during the survey period and to provide a basis for estimating future conditions of pollution under average or extreme flows such as experience may have shown are likely to occur.

One of the three major sections of the survey will be an extensive compilation of stream flow data for the Ohio and its main tributaries, to be furnished by the U. S. Engineer Corps through the office of the Division Engineer at Cincinnati, Col. E. H. Marks, and under the general and immediate direction of Capt. P. N. Strong and Principal Engineer R. L. Bloor respectively. This work will consist of the analysis of past flow records, showing the average and the 7-day minimum flows during each month of a term of years extending back from 1938, and also the compilation of daily flows, covering the entire period of the present survey, at a series of gaging stations located on the main stem of the Ohio River and at strategic points on its main tributaries. The work of obtaining these data will be aimed especially at showing average and minimum low-water flows, though the entire range of variations will be recorded for the period of the survey.

The very comprehensive data thus made available will be used as the basis of interpreting the laboratory observations in the various streams, both in showing the total quantities of polluting substances per day carried by them at different sampling points and in indicating the degree to which the observations will have to be corrected so as to convert them to terms of normal or minimum flow conditions for the purpose of estimating present or future requirements as to corrective treatment of polluting wastes.

LABORATORY SURVEYS

The first part of the laboratory surveys to be organized is that which deals with observations of pollution conditions in the main stem of the Ohio River, these observations being confined during the current year to the Kanawha-Kentucky River section, which comprises a length of about 280 miles along the middle third of the Ohio River proper. The lower half of this stretch, extending from Dam 33, near Maysville, Ky. to the mouth of the Kentucky River at Carrollton, Ky., will be covered from the laboratory at Cincinnati, where the analytical work will be performed. The upper half, extending from Dam 33 upstream to Dam 25, near Point Pleasant and above the mouth of the Kanawha River, will be covered by a floating laboratory which is being installed on the U. S. Quarterboat "Kiski", which has been loaned for the purpose by the U. S. Engineer Corps as a very substantial contribution to the laboratory work of the Survey.

In the Maysville-Carrollton stretch, the section extending from Dam 36 to Dam 37, in which heavy pollution enters from the Cincinnati Metropolitan District, will be studied more intensively than the remainder of this stretch. In the Point Pleasant-Maysville stretch, the section extending from Huntington to Portsmouth will receive similarly intensive study, as pollution is heavy in this area. In the Cincinnati pool, nine regular sampling stations have been planned, depending on the availability of motor-boat sample collection, and in the Huntington-Ironton section, ten stations have been planned, depending similarly on motor-boat collection. Above and below these two respective sections of the river will be sampling stations more widely spaced and located mostly at Government locks. Arrangements are being made for regular collection of samples by the lock personnel and their transportation to the laboratory by Public Health Service collectors, using automobiles This collection service has been made possible through the courtesy of the U. S. Engineer Corps, who have offered the excellent facilities of the Government lock personnel and equipment for this purpose.

ROUTINE LABORATORY DETERMINATIONS

The routine schedule of river water examinations will include the following determinations: (1) temperature, (2) turbidity, (3) alkalinity, (4) dissolved oxygen, (5) 5-day biochemical oxygen demand, (6) bacterial count, 24 hours at 37 °C., and (7) coliform group index. Determinations (2) and (3) will be made on samples collected only at one or two key stations from each laboratory. An effort is being made to ascertain whether it will be feasible to substitute gradually a direct-plate count for coliform bacteria instead of the usual enumeration based on fermentation tube tests. In order to establish when the use of modifications of the Standard Winkler procedure will be necessary in making dissolved oxygen determinations, semi-routine determinations of nitrite and also possibly ferrous and ferric iron will be necessary. Special determinations in the river water wil be needed occasionally for pH, CO_2 and acidity, particularly in waters affected by mill drainage and still mill wastes.

In studying the extent and nature of organic sludge deposits above certain dams, arrangements will be made for the regular collection of samples of these deposits by the Government lock personnel at intervals of one or two weeks during periods of low water and following periods of freshets. The primary object of these tests will be to ascertain the extent to which organic deposits are formed in the river during low stages and the extent to which they are removed by scouring action during freshets. In this connection, special attention will be given to sludge deposits formed above the higher permanent dams of which two have been constructed in the upper section of the Ohio. Considerable question exists as to whether deposits are completely removed by freshets from the pool, formed by these higher permanent dams, or whether there will be a tendency for these deposits to accumulate from year to year as the result of incomplete removal. Changes in the character of the deposits from low to high water periods can be gaged by tests of their total B.O.D. or oxidizability and indicators such as the percentage of volatile solids when figured on a dry basis.

Another special field of tests which can be carried out at the Cincinnati and floating laboratories will deal with the character of sewage and certain industrial wastes which may be important factors in the pollution of the river. These tests will necessarily be curtailed to the minimum essential requirements, such as total and volatile suspended matters, settleable solids and B.O.D. Data of this kind will be highly desirable

later in considering requirements and possibilities for sewage and industrial wastes treatment at different points. An important problem to be considered in this connection will be the possibilities for treating certain highly organic industrial wastes in combination with sewage.

TRIBUTARY STUDIES

Draining into the Ohio River between the mouths of the Kanawha and Kentucky Rivers are several important tributaries, including the Guyandotte, Big Sandy, Scioto, Little Miami, Licking and Miami Rivers. During the coming year an effort will be made to observe the sanitary condition of these tributaries in their more highly polluted sections, except in the Scioto, where an organized study has been in progress for more than a year past.

At the present writing, two alternative methods of making these observations are being considered. One would consist in operating one or more completely equipped mobile laboratory units, using automobile trailers or trucks, which would travel among the tributaries and collect and examine samples of river water and any important industrial wastes. Mobile units of this kind would be equipped for complete field examinations of samples, including determinations of D.O., B.O.D., 37° bacterial count and coliform group index. The alternative plan would involve using ordinary automobiles equipped with kits for certain tests, such as dissolved oxygen, pH value and alkalinity or acidity, which could be readily made in the field. Samples for more complete examination would be collected and tested at near-by water or sewage laboratories connected with treatment plants. The latter method may be preferable if a sufficient number of plant laboratories are available for the necessary, more complete tests.

Tests of Acid Mine Streams

Owing to the fact that neither of the two base laboratories will be located in the areas most affected by acid mine wastes, it will not be practicable to undertake any extensive observations of streams in these areas during the coming year, except in the Kanawha region, where an effort will be made to develop some systematic field observations based at the floating laboratory "Kiski" in order to provide a groundwork for more extensive observations, it is planned also to set up, under a

part-time compensation arrangement, some stream observations based at Morgantown, W.Va., at Norris, Tenn., at Pittsburgh or McKee sport, Pa., and possibly at a fourth point to be selected after consultation with the director of mine-sealing operations in these and other areas. The object of these observations will be to show acid conditions prevailing in some of the larger representative streams draining mining regions, in which fairly extensive mine-sealing operations have been completed and others draining near-by areas in which little or no mine-sealing has thus far been undertaken.

CONCLUSION

The essential difference between the present survey and those which have been made previously by the Public Health Service is that it will be concerned primarily with the more practical measures which may be necessary to correct undesirable conditions of stream pollution, wherever they may be known or found to exist in the Ohio River Basin, whereas the previous surveys have dealt primarily with establishing certain basic relationships and constants which underlie the pollution and natural purification of streams in general. The distinction here involved is that which may be said to exist between a practical situation and its specific remedy and a more general research problem, with its broader implications.

In the present instance the effort thus will be directed mainly to ascertain where actual conditions of pollution are undesirable and, wherever those conditions are observed, to establish a basis for estimating from the known facts concerning sources of pollution, the extent of corrective measures which may be necessary. In some cases the most important consideration involved may be excessive burden on water purification plants. Here the bacteriological and bioligical evidence will assume a primary role. In other cases it may be an undue burden on the oxygen resources of the stream, affecting the maintenance of normal aquatic life, the use of the stream for recreational purposes and perhaps even the general prevalence of nuisance conditions in the adjoining riparian areas. In this latter instance a study of the oxygen balance relationships and their restoration to a favorable status will be a primary consideration. Thus, it is evident that each local area of pollution will have to be studied more or less as an individual problem and the stream observations adjusted accordingly. Although detailed study of many such areas will be impracticable, in view of the limitations of available time and personnel, it should be possible to locate these areas and to show at least roughly where and to what extent corrective measures will be needed. The Survey

will afford an unparalleled proving ground for methods of evaluation which have been developed from previous studies of similar problems. It will be, in a sense, a new pioneering adventure, full of interest and action for those who will participate in it.

Memorandum No. 3

December 29, 1938

Instructions For Routine Bacteriological Examinations

MEMORANDUM NO. 3

December 29, 1938.

INSTRUCTIONS FOR ROUTINE BACTERIOLOGICAL EXAMINATIONS

In conducting the bacteriological examinations for the Ohio River Pollution Survey, the procedure given in Standard Methods for the Examination of Water & Sewage, Eighth Edition, 1936, of the American Public Health Association shall be followed. In cases where choices of equipment, material or procedure are offered, or where interpretation of the procedure given seems desirable, or where a deviation from the Standard procedure is to be made, the considerations which follow shall apply. Any deviations from the Standard procedure will be ir the nature of an increased requirement employed as a safety factor.

Sample Bottles: Eight ounce ground-glass stoppered wide-mouthed bottles shall be used.

Pipettes: The 1.0 ml. pipettes shall be graduated in 0.1 ml. and the spacing for the 0.1 ml. portion shall be at least 0.5 inch.

Dilution Bottles: Glass bottles with tight fitting cotton plugs and paper caps will be used, (observing the precautions cited in Standard Methods), unless the newly described rubber stoppers prove satisfactory after trial in the central laboratory at Cincinnati. In using cotton plugged bottles a circular motion of the mixture should be induced before vigorous mixing is started.

Petri Dishes: Side wall of petri dishes shall be 15. mm. high.

Fermentation Tubes: Durham type tubes shall be employed.

Hot Air Sterilization: Two hours at 170°C. shall be the required period and temperature.

Media: Bacto dehydrated culture media as supplied from the central laboratory shall be used for all purposes. Effort has been made to secure sufficient media from one preparation mixture to last throughout the entire investigation.

Steam Sterilization: All media, other than special media which may be employed at times, for which special instructions

will be given, shall be sterilized in the autoclave at 15 pounds live steam pressure for 15 minutes, observing the Standard precautions for expelling air, etc.

Dilution Water: Phosphate buffered distilled water, prepared in accordance with instructions in Standard Methods, Part III, Section XII, paragraph 1.2, shall be used. The stock phosphate buffer solution will be supplied from the central laboratory. (See Public Health Reports 48:681, June 16, 1933, Reprint No. 1580, for justification of use of such water for bacteriological examinations.)

Dilutions: The 99.0 ml. portion of dilution water only, will be employed. Intermediate portions in a decimal series of dilutions will be obtained by measuring 0.1 ml. portions directly from the sample or dilution thereof concerned. Experience has shown that, when this precedure is followed with precise technique, employing the 1.0 ml. pipettes required above, the error involved is not as great as when attempts are made to provide and use exactly 9.0 ml. portions of dilution water.

Shaking: In shaking samples or dilutions of samples prior to withdrawal of portions for planting or further dilution, the agitation applied should be vigorous. An addition to the Standard requirement of shaking 25 times, that this be accomplished in 30 seconds when the bottle is moved each time through a space of at least 4 inches, has proved adequate.

Transfer of Portions: In transferring portions of a sample or of dilutions of a sample a fresh sterile pipette of appropriate size should be used for each dilution. On introducing the pipette into the sample for the withdrawal of a portion, the tip shall not be allowed to descend into the sample or dilution thereof more than about 0.5 inch. This precaution is essential as occasionally samples are of such a nature that considerable material will adhere to the outside of the pipette and drain off with the measured portion when it is delivered. Similarly, when portions of a sample or dilution thereof are delivered to dilution bottles the polluted tip of the pipette should not be allowed to touch the neck of the dilution bottle as it enters or as it leaves the bottle. In making the delivery the tip of the pipette shall be brought into contact with the surface of the dilution water, but not allowed to descend into the water. With cotton plugged dilution bottles preliminary mixing of the sample with the dilution water should be accomplished before the cotton plug is wetted by the vigorous agitation specified.

In delivering portions of a sample or dilution thereof to petri dishes the tip of the pipette should be allowed to touch the plate only once in making the delivery. Similarly, in delivering a portion to a broth tube the tip of the pipette shall be placed near the surface of the broth in the tube as delivery is made. This prevents erroneous results due to the adherence of portions of the sample or dilution to the sides of the broth tube above the level of the broth. Organisms cannot demonstrate their presence unless they are actually introduced into the broth.

Delivery from pipettes shall always be made from meniscus to meniscus. Delivery or blow-out pipettes will not be employed and in delivering portions the flow of the liquid shall not be speeded by jerking or blowing. In general, 1.0 ml. pipettes will be employed for measuring 1.0 and 0.1 ml. portions; 2.0 ml. pipettes for 1.0 and 2.0 ml. portions, never for 0.1 ml. portions; and 10.0 ml. pipettes only for portions larger than 1.0 ml.

Examinations: The routine bacteriological examinations to be made on this survey will be (1) total counts of the number of bacteria growing on agar when incubated at 37°C., for 24 hours, and (2) an enumeration of the number of organisms of the coli-aerogenes group of bacteria. Additional special examinations or confirmations which may be instituted as the work progresses will be covered in subsequent memoranda.

Plating: When the portion of sample or dilution thereof is added to the petri dish no more than 15 minutes shall be allowed to elapse before fluid agar at the required temperature is added, thoroughly mixed with the portion and allowed to solidify.

In making plates, two plates containing duplicate portions of the water under examination, which will give colony counts within the prescrived limits, shall be made and also a third plate containing one-tenth or ten times this amount, depending on whether in the judgment of the bacteriologist the count from the duplicate plates will be more than or less than the limiting number. If the number of colonies developing from the samples of a given station are so erratic that the results from the duplicate plates are frequently indeterminate, or if the sample is a new one from an unknown source, then more than one pair of duplicate plates should be made. In making counts of plates a standard illuminated counter will be used.

Supplemental instructions governing the prescribed limits for the permissible number of colonies per plate, the computation of the average bacterial count, and a list of the symbols employed

in obtaining and recording results are appended to this memorandum

Tests for Members of the Coli-aerogenes Group: Routine tests as made for this group of bacteria in this study will be limited to the results of the Presumptive and Confirmed Test as given in Standard Methods. The confirmatory test for routine work will be limited to the demonstration of gas production in any amount in 48 hours in the liquid confirmatory medium employed, brilliant green bile (2%) lactose broth. A 3.0 mm. loop will be used for the transfer from lactose broth to the confirmatory medium.

In making inoculations of primary lactose broth tubes for the determination of coli-aerogenes group organisms, three duplicate tubes at each of three decimal dilutions shall be planted. Dilutions for this planting should be selected so that all of the three tubes in the lower dilution will be positive and all tubes in the higher dilution negative, with the results in the intermediate dilution variable. Whenever the results from a given station vary from this ideal to the extent that the results may be indeterminate, i. e. either all positive or all negative, then a fourth dilution should be added to the series of dilutions either higher or lower than the others, depending on the judgment of the bacteriologist. Only tubes of the highest dilution, showing gas formation in lactose broth, shall be transferred for confirmation, except that all tubes negative for gas after 24 hours of incubation, but positive for gas after 48 hours, shall be confirmed. A positive presumptive tube shall always be recorded as positive for the presence of members of the coli-aerogenes group of bacteria, unless confirmation has been tried. That is, the fact that a high dilution tube has failed to confirm cannot be accepted as evidence that a lower dilution gas producing tube, prepared from the same sample, would also fail to confirm. Results obtained will be interpreted in terms of the most probable numbers of coli-aerogenes organisms present, in accordance with the tables given by Hoskins (Public Health Reports, 49:393, March 23, 1934, Reprint No. 1621.) A copy of this reprint will be supplied to each bacteriologist.

Records: When samples arrive in the laboratory pertinent data regarding them shall be entered in a serially numbered log book by the collector and the serial number written on the bottle. The serial number thus assigned to each sample will identify the sample and this number shall appear on each tube, plate or record employed in connection with the sample.

The pertinent data indicated should include adequate information regarding the source of the sample, the time of collection, the name of the collector and the temperature of the water at the time of collection. If any unusual conditions, which might affect either the sample or the envirement at the point of collection, are noted, this information should be entered in the log under "Remarks."

All pertinent data concerning the sample and all results secured in connection with the bacteriological examination of a sample shall be entered on the record cards no erasures shall be made. If an erroneous entry is noted it should be circled and if the correct result is known it should be entered at the nearest available space. The correct result thus entered should be O.K'd by initialing.

RULES GOVERNING THE COMPUTATION OF THE AVERAGE SOLID MEDIUM BACTERIAI COUNT OBTAINED ON PLATES IN USE AT THE U. S. PUBLIC HEALTH SERVICE STREAM POLLUTION INVESTIGATIONS LABORATORY CINCINNATI, OHIO

1. Average for plate counts shall be based on plates which give counts in the range covered by 25 to not more than 400 colonies per plate.

2. When the duplicate plates in a series of three show between 25 and 400 inclusive, colonies per plate, and the third plate less than 25 or more than 400 colonies, the third plate should be omitted from the average unless it falls between the other two.

Examples:

(a)

0.01	c.c.	92	
.01	"	76	
.001	"	6	(omit)
Result		8400	per c.c.

(b)

.1	c.c.	857	(omit)
.01	"	127	
.01	"	156	
Result		14100	per c.c.

(c)

.01	c.c.	92	
.01	"	76	
.001	"	9	(intermediate between duplicate parts)
Result		8600	per c.c.

3. Where the duplicate plates both show too many or too few colonies, only the third plate should be considered in the average result.

Examples:

(a)

0.01	c.c.	847	(omit, too many)
.01	"	732	" " "
.001	"	95	
Result		95000	per c.c.

(b)

.1	c.c.	65	
.01	"	8	(omit, too few)
.01	"	7	(omit, " ")
Result		650	per c.c.

4. Where one of the duplicate plates gives an obviously erroneous count it should be disregarded in recording the average result.

Example:

.1	c.c.	68	
.1	"	29	(spreaders) (omit)
.01	"	10	(omit, too few)
Result		680	per c.c.

5. When one of the duplicate plates comes within the prescribed limits and the other shows too many or too few colonies, both plates must be either included in or excluded from the average as follows, except as indicated under 4: (a) where the average of the two duplicate plates falls within the limits, both shall be included in the average and (b) when the average of the two falls outside

the limits, both shall be excluded.

Examples:

(a)

0.01	c.c.	422)	(average 397, within limit, a[ll] plates included in average)
.01	"	372)	
.001	"	39	
Result		395	

(b)

.1	c.c.	255	
.01	"	26)	(average 24, not within limit both of duplicates excluded)
.01	"	22)	

6. When more than one set of duplicate plates is made, equal authority should be given to each set, providing the number of colonies on the plates falls within the prescribed limits

EXPLANATION OF SYMBOLS USED IN OBTAINING AND RECORDING BACTERIOLOGICAL RESULTS

For Broth Tubes

0 Indicates no apparent growth.

- Indicates no gas production.

b Indicates small amount of gas which remains in spherical form at top of tube.

$\pm$ Indicates an amount of gas greater than "b", but less than 10 per cent.

+ Indicates an amount of gas varying from 10 to 49 per cent.

# Indicates an amount of gas varying from 50 to 100 per cent.

For Confirmatory Plates

0 Indicates sterile plate, no growth.

- Indicates plate with non-typical

$\pm$ Indicates plate with questionable typical growth.

+ Indicates plate with typical colonies.

For Designating Quantities Planted

On record cards portions of sample examined shall be indicated by the decimal system as 10., 1.0, 0.1, 0.01, 0.001, 0.0001, etc. ml. On plates or tubes, where there is a possibility of accidental erasure of some of the figures in handling, the 0.001 ml. portion should be marked 2; the 0.0001, 3; the 0.00001, 4; etc. This system can be easily remembered by noting that the numerals 2, 3, 4, etc. represent the number of ciphers between the decimal point and the unit figure.

Most probable numbers per ml. of sample, planting 3 portions in each of 3 dilutions in geometric series
L = Largest portion M = Middle portion S = Smallest portion

No. of Positive Tubes L M S	3-10 3- 1 3- .1	3-1 3-.1 3-.01	3-.1 3-.01 3-.001	3-.01 3-.001 3-.0001	No. of Positive Tubes L M S	3-10 3-1 3-.1	3-1 3-.1 3-.01	3-.1 3-.01 3-.001	3-.01 3-.001 3-.0001
0 0 0	--				1 2 0	.11	1.1	11	110
0 0 1	.03	.3	3	30	1 2 1	.15	1.5	15	150
0 0 2	.06	.6	6	60	1 2 2	.20	2.0	20	200
0 0 3	.09	.9	9	90	1 2 3	.24	2.4	24	240
0 1 0	.03	.3	3	30	1 3 0	.16	1.6	16	160
0 1 1	.061	.61	6.1	61	1 3 1	.20	2.0	20	200
0 1 2	.092	.92	9.2	92	1 3 2	.24	2.4	24	240
0 1 3	.12	1.2	12	120	1 3 3	.29	2.9	29	290
0 2 0	.062	.62	6.2	62	2 0 0	.091	.91	9.1	91
0 2 1	.093	.93	9.3	93	2 0 1	.14	1.4	14	140
0 2 2	.12	1.2	12	120	2 0 2	.20	2.0	20	200
0 2 3	.16	1.6	16	160	2 0 3	.26	2.6	26	260
0 3 0	.094	.94	9.4	94	2 1 0	.15	1.5	15	150
0 3 1	.13	1.3	13	130	2 1 1	.20	2.0	20	200
0 3 2	.16	1.6	16	160	2 1 2	.27	2.7	27	270
0 3 3	.19	1.9	19	190	2 1 3	.34	3.4	34	340
1 0 0	.036	.36	3.6	36	2 2 0	.21	2.1	21	210
1 0 1	.072	.72	7.2	72	2 2 1	.28	2.8	28	280
1 0 2	.11	1.1	11	110	2 2 2	.35	3.5	35	350
1 0 3	.15	1.5	15	150	2 2 3	.42	4.2	42	420
1 1 0	.073	.73	7.3	73	2 3 0	.29	2.9	29	290
1 1 1	.11	1.1	11	110	2 3 1	.36	3.6	36	360
1 1 2	.15	1.5	15	150	2 3 2	.44	4.4	44	440
1 1 3	.19	1.9	19	190	2 3 3	.53	5.3	53	530

Sheet No. 2

No. of Positive Tubes L M S	3-10 3- 1 3- .1	3-1 3-.1 3-.01	3-.1 3-.01 3-.001	3-.01 3-.001 3-.0001
3 0 0	.23	2.3	23	230
3 0 1	.39	3.9	39	390
3 0 2	.64	6.4	64	640
3 0 3	.95	9.5	95	950
3 1 0	.43	4.3	43	430
3 1 1	.75	7.5	75	750
3 1 2	1.20	12.0	120	1200
3 1 3	1.60	16.0	160	1600
3 2 0	.93	9.3	93	930
3 2 1	1.50	15.0	150	1500
3 2 2	2.10	21.0	210	2100
3 2 3	2.90	29.0	290	2900
3 3 0	2.40	24.0	240	2400
3 3 1	4.60	46.0	460	4600
3 3 2	11.00	110.0	1100	11000
3 3 3	- -	- -	- -	- -

Memorandum No. 4

January 6, 1939

Outline of Chemical Methods

Memorandum No. 4

January 6, 1939.

OUTLINE OF CHEMICAL METHODS

The routine chemical analysis to be made on water samples during the Ohio River Pollution Survey will include the following determinations: Turbidity, alkalinity (and/or acidity, if indicated), total and volatile suspended solids, pH, nitrite nitrogen, dissolved oxygen and 5-day biochemical oxygen demand. The dissolved oxygen shall be determined on individual samples collected at each point of every sampling section or station. Biochemical oxygen demand shall be determined on the total composite of the left, center and right point samples at each sampling station. If a sample from only one point is collected at any sampling station, the B.O.D. must be determined on it.

Nitrite determinations are to be made to determine what method must be used in making the dissolved oxygen determinations If the dissolved oxygen determinations are to be made in the field to the point of titration (at points most distant from the central laboratory) then the nitrite determination must also be made in the field. In all samples where .05 p.p.m. or more nitrite is found, a procedure for destroying nitrite must be used before dissolved oxygen is determined. If less than .05 p.p.m. of nitrite is found, the unmodified Winkler method may be employed. If, after a period of daily nitrite examinations, it is found that most sampling points are likely to contain nitrite above .05 p.p.m. at times, it will be best to adopt the corrective procedure in all cases and to eliminate the nitrite determinations.

Turbidity, alkalinity, total and volatile suspended solids and pH determinations will be made only on samples from special designated stations. The water sample for these determinations may be poured from the sampling can into a wide mouth 32 oz. bottle and transported to the laboratory. At stations where three points on a section of the river are being sampled, this bottle shall be poured about one-third full at each point from a measure, provided for the purpose, full of water taken from the sample collector by dipping. In all of these determinations the methods described in Standard Methods for the Analysis of Water and Sewage, Eighth Edition, will be used as far as possible. A brief description of these procedures, with detailed instructions in any cases of deviation from these methods, follows:

Turbidity

The square 32 ounce bottles containing the special samples may be compared with standards of silica suspensions prepared in the same kind of bottles for turbidities of 25 p.p.m. and less. The standard candle turbidimeter shall be used to determine turbidities of over 25 p.p.m., the vanishing point taken as the depth of sample at which the image of the standard candle flame first becomes evenly diffused over the entire cross section of the tube.

Hydrion Concentrations (pH)

The pH determination shall be made electrometrically using the glass electrode. (A Leeds and Northrup Universal pH indicator will be supplied to the boat for this purpose and the L. & N. meter using the old, larger glass electrodes will be available at this Station.) When the calomel and glass electrodes have been prepared and the meter has been assembled, the following precautions should be observed in making a pH reading. First, the vessel which is to contain the sample for measurement must be thoroughly cleaned. It should be rinsed once with distilled water and once with the sample to be examined before it is filled with sample. The temperature of the sample should be taken at this point and the temperature compensation dial on the meter adjusted properly. The dry cells or other source of E.M.F. are then balanced against the standard cell of the meter by intermittently pressing the key marked S.C. and adjusting the variable resistance until no deflection is obtained on the galvanometer. The pH of the sample may then be determined by intermittently pressing the key marked pH and adjusting the pH scale until the galvanometer shows no deflection. When no deflection of the galvanometer is obtained by pressing the pH key the scale reading indicates directly the pH of the sample. If the dry cells cannot be balanced against the standard cell, the dry cells are run down and must be replaced before a pH reading can be obtained. On any sample in which the pH is found to be 5.1 or less, a determination for acidity is indicated.*

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* At points in the upper stream where acidity determinations are necessary, this determination should be made by titration of hot and cold portions of sample with phenolphthalein and by titration of a cold portion using methyl red as an indicator. Methyl red with a color change at a pH of 5.1 should not be substituted for methyl orange in the alkalinity determination. Neither should methyl orange with a color change at pH 4.0 be substituted for methyl red in the acidity determination.

Alkalinity

The alkalinity should be determined oh a portion of the special composite sample from the 32 ounce bottle. The Standard Method should be used, employing N/50 $H_2 SO_4$ and methyl orange indicator.

Total and Volatile Suspended Solids

The suspended solids should be determined by filtering 50 to 100 ml. of the special sample, with suction, through a Gooch crucible which has been prepared with an asbestos mat, dried, ignited and weighed. After filtration the crucibles are dried at 103 to 105° C. for 2-1/2 hours, celled in a desiccator and weighed. The crucibles are to be ignited at 600° C. for 10 to 15 minutes in the muffle furnace at the main laboratory and may be heated at dull red heat with a Meeker burner on the boat in determining the volatile suspended solids.

Nitrite Nitrogen

This test, employing the Standard Method, is to be carried out in the field or immediately after the samples arrive at the laboratory, but in any case before the D.O. determination is started. For the field test, our sample collector should be provided with the reagents for making this test (sulfamilic acid solution and anaphthylamine acetate solution) together with the necessary standard solution, 2-500 ml. bottles of distilled water, a number of pipettes and two 100 ml. low form Nessler tubes. All of this material, along with the reagents for making the D.O. determinations will be carried in a special kit provided for that purpose. The nitrite test should be made on the composite sample at each sampling station as soon as the sample is collected. This test shall be directed to determine whether or not nitrite is present rather than to determine the exact amount present. Consequently, only one standard of .05 p.p.m. will be required and it will be necessary only to determine whether or not the nitrite nitrogen content is less than .05 p.p.m.

Dissolved Oxygen

Because of the probability of encountering the various interfering substances in any investigation of the scope of Ohio River pollution survey, it is impossible to select one procedure

for dissolved oxygen that will be applicable in all cases. Other interfering substances besides nitrite, such as ferrous and ferric salts, organic matter and sulfite wastes, may be encountered in samples from some points and the chemist must be on the alert for evidences of these materials so that the best corrective procedure for any particular material may be applied. On all upper river sampling points the chemist should make ferrous and total iron determinations before the method of determining dissolved oxygen is selected.

The following procedures are all applicable under certain circumstances. These are listed in the order of their simplicity and the special conditions under which they should or should not be applied:

(1) Regular Winkler Method (See pages 144-145 Standard Methods) This method should be applied on samples from all points of the main stream which contain less than .05 p.p.m. of nitrite, 1.0 p.p.m. of ferrous iron and 10 p.p.m. of total iron. On all of the lower river points the iron content will probably be lower than the above limits so that the nitrite test will determine whether the regular Winkler method should be used.

(2) Short Winkler Method This method should be applied to samples containing mud or sludge where the limits mentioned above for nitrite and iron are met, but where a large amount of interfering organic matter is present. Consequently, it will rarely be necessary to use this method on Ohio River samples.

(3) The Alsterberg Sodium Azide Procedure This procedure should be applied on Ohio River samples where the iron content meets the limits stated under (1), but where more than .05 p.p.m. of nitrite nitrogen is found. The detailed procedure for this method is given in the Analytical Edition of the Journal of Industrial and Engineering Chemistry, Vol. 10, No. 12, page 701 (1938).

(4) The Rideal Stewart Modification should be used on any Ohio River samples which contain appreciable (1.0 p.p.m. or more) amounts of ferrous iron. As each p.p.m. of ferrous iron would produce an apparent loss of .14 p.p.m. of dissolved oxygen, one part is taken as the upper limit of tolerance for the ordinary Winkler or Alsterberg procedure. If more than 1.0 p.p.m. is present this should be oxidized by the acid permanganate

following the Rideal Stewart procedure (pages 147-148 Standard Methods).

(5) The Alkaline Hypochlorite Modification This method may be necessary at sampling points where considerable quantities of paper mill wastes are encountered.

5-day Biochemical Oxygen Demand

The 5-day biochemical oxygen demand determination shall be made according to the standard method, except in the following details of procedure:

I - The phosphate buffered formula C water[1] shall be used wherever dilution of samples is required. The four solutions required to make up this dilution water are:

(A) Ferric chloride - 0.27 g. $Fe\ Cl_3\ .6\ H_2O$ per liter

(B) Calcium chloride - 18.3 g. $Ca\ Cl_2\ .4\ H_2O$ per liter

(C) Magnesium sulphate - 9.9 g. $Mg\ SO_4\ .7\ H_2O$ per liter

(D) Phosphate buffer - 34.04 g. $KH_2\ PO_4$ and 175 ml. of N/1 NaOH per liter

The following amounts of each of these solutions are added to distilled water, free of copper, to prepare the dilution water

(A)	0.5 ml.	per	1.	or 8.0 ml.	per	16	1.	carboy
(B)	2.5 ml.	"	1.	"40.0 ml.	"	16	1.	"
(C)	2.5 ml.	"	1.	"40.0 ml.	"	16	1.	"
(D)	1.25 ml.	"	1.	"20.0 ml.	"	16	1.	"

The bicarbonate dilution water of Standard Methods shall not be used.

II -The incubation bottles should be 250 ml. capacity, with ground-glass stoppers, cleansed with concentrated sulphuric acid, carefully rinsed and dried before use. Water seals may be dispensed with except during the summer months when

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(1) Theriault, E. J., McNamee, P. D., and Butterfield, C. T. Experimental Studies of Natural Purification in Polluted Waters. V. Selection of Dilution Water for Use in Oxygen Demand Tests. Public Health Reports 46, 1084-116(1931).

undiluted river water with an initial temperature higher than 20°C. is to be incubated. On any special B.O.D. work in which a series of bottles are incubated for long periods it is desirable to water seal the bottles during incubation.

III- On any sample in which the pH is found to be below 6.0 it will be necessary to adjust the pH to 7.0 to 7.2 with N/10 NaOH before incubation for biochemical oxygen demand. After the pH adjustment has been made, the sample should be reseeded with river water at a normal pH. About 20 ml. of river water per liter of sample or about 5 ml. for an individual D.O. bottle should be used for seeding.

IV- Where it is necessary to dilute the sample before incubation, the dilution technic employed should not reaerate the diluted sample. This procedure is chosen in order that a calculated initial dissolved oxygen content of the diluted sample may be made from the known dissolved oxygen content of the sample and the dilution water, if it is desired. For this reason, the dissolved oxygen content of the dilution water used with any sample must always be determined and recorded on the sample card. It will probably be found that 50 percent dilution will usually suffice on Ohio River samples that require dilution. In rare instances it may be necessary to make a 33-1/3% or even a 25% dilution of the sample. When the dilution factor has been decided it should be recorded and the proper volume of sample should be siphoned into a one liter cylinder. Dilution water is then siphoned into the cylinder to the one liter graduation, being delivered below the surface of the liquid, and the dilution is thoroughly mixed without aeration with the special stirring device. After mixing, the sample is immediately siphoned into three properly labeled 250 ml. B.O.D. bottles. If the diluted sample contains considerable settleable suspended matter, the stirring should be continued while the sample is being siphoned into bottles. The dissolved oxygen content of one bottle is determined at once. The other bottles are incubated at 20° C. for five days and the final dissolved oxygen content is then determined. If the amount of other work required makes it necessary, the check bottle, after incubation, may be eliminated. In making the dissolved oxygen determinations for the B.O.D. test the sodium azide modification of the Winkler procedure should be used when necessary, in order to eliminate interference due to nitrites that may be formed during incubation.

V - If the initial mean dissolved oxygen content of the water at any sampling section is over 9.5 p.p.m. the oxygen content of the water shall be reduced before the sample is incubated for the B.O.D. determination. In such cases the water sample for the B.O.D. composite is poured into a bottle about twice the size necessary to hold it. The stoppered bottle is then carefully warmed in a water bath until the temperature of the sample reaches 20 to 30° C. The bottle is then vigorously shaken for several minutes to remove the excess oxygen. After shaking the sample is cooled to 20° C. and siphoned into 250 ml. B.O.D. bottles. The initial dissolved oxygen content is determined on one of these and the others are incubated at 20° C.

Memorandum No. 5

January 12, 1939

Instructions Concerning The Use Of
Bacto-Brilliant Green Lactose Bile Agar For The
Enumeration of Organisms Of The Coli-Aerogenes Group of Bacteria

Memorandum No. 5

January 12, 1939

INSTRUCTIONS CONCERNING THE USE OF BACTO-BRILLIANT GREEN LACTOSE BILE AGAR FOR THE ENUMERATION OF ORGANISMS OF THE COLI-AEROGENES GROUP OF BACTERIA

Comparative results on the enumeration of coli-aerogenes group bacteria in river water obtained, (1) by the Standard procedure using lactose broth as a primary medium, with three duplicate tubes at each dilution in three or more decimal dilutions of a sample, and (2) by plate counts from the same samples using a differential plating medium, Bacto-Brilliant Green Lactose Bile Agar, have indicated a very high degree of correlation.

As results by the direct plating method are much easier to obtain and are not subject to the errors common to the dilution method, this procedure will be followed for the enumeration of members of the coli-aerogenes group of bacteria for samples from certain sampling points in the Ohio River Pollution Survey, either in addition to the determination as made by the Standard procedure, or with the exclusion of the determination by the Standard procedure. The sampling points from which samples will be examined for coli-aerogenes group bacteria by the direct plating method and instructions as to whether this method shall be used in addition to, or to the exclusion of the Standard procedure, will be set forth in subsequent communications.

Procedure to be followed: In general the procedure for making plate counts after 24 hours incubation at 37° C., as given in Standard Methods and as interpreted in Memorandum No. 3 (December 29, 1938), will be followed. Certain detailed items of technique, which apply to this direct plating procedure, will now be given.

Preparation of Medium: All media for this study will be prepared from dehydrated Bacto-Brilliant Green Lactose Bile Agar (Serial No. 36793) in accordance with the instructions given, (Reference Noble & Tonney, Jour. A.W.W.A. 27:108: 1935). Single strength medium, which is to be used for planting 2. ml. or less portions, is prepared by dissolving with heat 20.6 grams of dehydrated powder in 1000. ml. of distilled water. Care must be exercised to prevent the powder burning on the bottom of the vessel before it is entirely dissolved. As soon as the powder is completely

dissolved, mix thoroughly and distribute into agar bottles, putting 50 to 150 ml. in each bottle, depending on the daily requirement of the particular laboratory. Cotton plug, paper cap and mark the bottles as for Standard agar. Sterilize at 15 lbs. live steam pressure for 15 minutes. (The time requirement of 20 minutes cited on the container presupposes the availability of live steam from pressure lines. With our conditions, requiring a longer period for the development of 15 lbs. of steam pressure when the steam is generated in the autoclave, a 15 minute interval, after the correct pressure has been reached, has been found sufficient). Medium, thus sterilized, will be stored in the refrigerator until required for use. This period of storage should not exceed 10 to 14 days as it will deteriorate after this period.

Planting: The general instructions referred to will be followed Portions of samples, (diluted if necessary), should be planted of such volume that the counts obtained for members of the coli-aerogenes group will be within the range of 25 to 400 colonies per plate. The ideal range of colonies per plate is from 50 to 150. As many pairs of duplicate plates as necessary, to obtain counts within the permissible limits, may be planted, but it should be possible after experience with the particular samples under investigation to limit this number to two pairs.

Sufficient agar at a temperature of 40 to 41° C. should be poured into the plates to provide for a uniform depth of agar of approximately 0.3 cm. in the finished plate. This will require 15 to 20 ml. of agar per plate depending on the diameter of the particular petri dishes employed.

Incubation and Counting: Plates, thus made, will be incubated at 37° C. for 16 to 18 hours before counting. They should be counted during the interval between 16 and 18 hours of incubation as prior to this period all colonies may not be characteristically visible and after this period extraneous colonies, whose appearance may be confusing, may appear. In counting the colonies, an illuminated counter provided with a white or silver-gray background should be employed.

As the bacterial content of a sample may change quite rapidly, the samples should be planted as soon as they arrive in the laboratory. Where comparative coli-aerogenes group enumerations are being made with the results obtained (1) by the direct plating method and (2) by the Standard lactose broth enrichment method, plantings should be made for both enumerations

at the same time. These requirements, if the sample should arrive in the laboratory during the morning hours, say 10 A.M., would mean that the 16-18 hour period of incubation would be fulfilled at an inopportune time, namely at 2 to 4 A.M. of the following day. To provide for these difficulties and at the same time meet the incubation requirements, the Brilliant Green Lactose Bile Agar plates may be placed in the refrigerator immediately after they are planted and solidified. At this stage the bacterial cells from the sample are held fixed in the agar and growth, as thought of in terms of 37° C. incubation, is stopped. Plates held thus in the refrigerator may be placed in the 37° C. incubator at 3 P.M. and the 18-hour incubation period will then be complete at 9 A.M. the next day. For plates that have been chilled in this manner in the refrigerator, approximately an 18-hour period of incubation should probably be allowed, rather than 16-18, as it will take approximately an hour for the cold plates to get to incubation temperature. Experience with counting and with the particular refrigerator available will indicate the proper time interval to the bacteriologist.

Recognition and Identification of Colonies: While colonies formed by members of the coli-aerogenes group of bacteria in this medium do have a characteristic morphology and a black to red color, familiarity with their appearance can be obtained more definitely with visual inspection and testing than by attempts at verbal description. This knowledge should be obtained in two ways: (1) by planting pure cultures of coli-aerogenes bacteria, in appropriate dilution, and observing carefully the appearance of the colonies; and (2) by picking colonies on plates made from natural samples for confirmation. To carry out this latter procedure, all of the colonies counted from a given area on a plate (10 is an appropriate number) should be picked to brilliant green bile lactose broth for partial confirmation. The production of gas in any amount in this broth, after 24 to 48 hours of incubation at 37° C., shall be accepted as evidence that the colony picked contained some member of the coli-aerogenes group of bacteria.

To insure fairness in the identification and to avoid the selection of particular types of colonies, an area should be circumscribed on the bottom of the plate enclosing about 10 colonies which have been counted and all of the colonies enclosed within this area which have been included in the coli-aerogenes count should be picked. This procedure should be followed with each sample and records kept of the results

until the bacteriologist has established a high degree of accuracy, at least 90 per cent, in the selection of the colonies counted.

Recording of Results: The rules given for the recording and averaging of results in Memorandum No. 3 shall be applied to results obtained with this special medium.

Memorandum No. 8

March 1939

Collection And Examination of Biological Samples

and

Supplement on Points To Be Covered

Memorandum No. 8

March, 1939

COLLECTION AND EXAMINATION OF BIOLOGICAL SAMPLES

In the following memorandum, detailed directions are given concerning the collection and biological examination of river water and bottom sediment samples. It is desirable, in this connection, to note here very briefly, the broad objectives of the biological examinations in a survey of the general character represented by the one now in progress in the Ohio River Basin.

These objectives may be stated as follows, having in mind the essentially practical nature of the present survey:

1. A study of the distribution of pollution and non-pollutional organisms in the river water and in the bottom sediments, both in the more highly polluted sections of the river and in those affected more remotely by pollution. In this connection, reference may be made to the results of previous observations in the Ohio and Illinois Rivers.

2. A survey of stream sections affected by certain type of industrial pollution, such as acid mine, tannery, paper pulp, soap, chemical and other similar wastes, with a view to estimating the extent to which these waters may interfere with the normal distribution and functions of organisms which are concerned in natural purification of the stream.

3. A special study of the occurrence of organisms in the river causing tastes and odors in water supplies, or interference with the economical purification of water supplies. This would include a consideration of pollution and other conditions in the river which might have a bearing on the prevalence of taste-producing or filter-clogging organisms.

The present survey differs very markedly from previous studies of the Ohio River in that it is not primarily a research project. It is concerned with locating seriously polluted stretches of the Ohio and its tributaries and with obtaining the observational data necessary to estimating the nature and extent of corrective measures which will be required in each situation for restoring a stream to a reasonable degree of cleanliness, having in mind the more essential water uses of the particular stream. For this reason it is not proposed to undertake establishing any extensive array of new facts or prin-

ciples bearing on the fundamental nature of stream pollution and purification phenomena, but rather to utilize those facts which are already know as the basis of evaluating the specific problems of stream pollution which now exist in the Ohio River and its tributaries. This general viewpoint may be said to be a guidepost for all of the laboratory studies connected with the present survey, including the biological studies.

A. Plankton Samples

For the present, the regular bacteriological samples will serve as plankton samples also.

On arrival of these bacteriological samples at the laboratory, or at the laboratory boat "Kiski", the biologist, if present, will arrange, with cooperation of the officer in charge to secure a portion (about 100 cc or more) of the sample.

If the biologist is located elsewhere temporarily, (perhaps on field duty) the person in charge of the samples, or some person designated by the Director of the Laboratory, should procure the plankton samples from the bacteriological samples as follows:

1. Compositing of samples, if necessary* should be done as soon as possible after arrival of the samples.

2. One hundred cc or more of the composited water is to be dosed with 3 cc of formalin, labeled stating station and date, and set aside for the biologist when he shall arrive.

3. In any case, 100 cc is the minimum amount required for a plankton sample. If the biologist is present, he will centrifuge the 100 cc sample at once, and will examine the unkilled catch. In case of 2 or more samples requiring attention at the same time, the unkilled 100 cc sample is to be placed in the ice box until it can be centrifuged.

B. Bottom Sediments (To be collected once a month at selected stations.)

Equipment Required:

One small dredge, or a mushroom-shaped mud scoop, with 50 or 60 foot line attached, 1 small curved garden trowel or stout dipper, strips of tough

* Necessary only in case of E. C. & W. samples.

white paper about 1 x 5 inches (for labels) and mason quart jars, one for each sample, with about 80 cc of formalin in the jar.

Procedure:

(1) Throw the scoop out, harpoon fashion, as far as possible from the boat. When the scoop has reached bottom drag it 5 or 6 feet to secure a bottom sample. Pull the scoop and contents aboard.

(2) With trowel or dipper select portions of the mud in the scoop representative of the entire catch and drop these selections in the jar. (Guard against splashing formalin in your face.) Make the jar three-fourths full, or more.

(3) Using a soft lead pencil (do not use indelible), write the station, the location in channel (E. C. or W.) and the date, and drop this label in the jar. Deliver the sample to the biologist, or to the man who transfers samples to the laboratory.

(4) If the sampler brings up pebbles, rubbish, fungus-like masses attached to stones or sticks, etc. include a fair proportion of these things in the jar sample.

(5) Bottom sediments are sometimes swept away by flood conditions. The first try may fail to get a bottom sample. Try another portion of the channel. Get the sample if possible. This is important.

(6) Discard mud remaining in sampler, rinse this, coil line, and have everything ready for taking the next sample.

C. Examination of Samples (Plankton)

1. Concentration

Mix the sample thoroughly by gentle agitation. Place a measured amount, 100 cc if possible, in centrifuge tubes, and centrifuge for five (5) minutes at high speed (about 3500 r.p.m.). Pour off excess water and remove the catch (by catch is meant the concentrated contents of the entire sample) from the centrifuge tubes to a bottle or vial already provided with a label

stating the station, the date, and the concentration of the catch. Get all of the catch from the tubes by rinsing with a half cc of clean water, adding this rinsing to the catch already in the vial. The total amount of the catch is now measured, using, for convenience, a 10 cc delivery pipette. If (a) the amount is, for example, 4½ cc. sufficient water should be added to eliminate the fraction, thus making 5 cc. (b) If the amount be 8 or 9 cc. it is advisable to add enough water to bring the total volume up to 10 cc. This data should be added to the label: "100 cc to 5 cc" or "100 cc to 10 cc." This statement of concentration means that by counting all the organisms in all of the catch, we thus ascertain the total content of the 100 cc sample of water. Similarly, if we count the organisms in 1 cc of the catch in (a) above, we thus ascertain the content of one-fifth of the original water, or 20 cc.

2. The Count

The Counting-Cell Method: The microscopical examination or counting is accomplished as follows, using the Sedgwick-Rafter counting cell, which holds 1 cc and has a depth of exactly 1 millimeter:

(a) Thoroughly, but gently, mix the entire catch.

(b) Using a graduate pipette which does not have a fine tip (this may be broken or filed off) deliver 1 cc of the mixed catch to the cell.

(c) Affix the glass cover by a side-ways motion of this cover, as suggested by (a) Whipple.

(d) With a low power microscope (about 20 or 30 diameter) examine the entire cell, moving it back and forth across the stage and inspecting every portion of the 20 x 50 millimeter area thus presented. This is a search for any relatively large organisms, such as caustacea, rotifers, small worms and certain plant forms. Tabulate the number and kinds of these larger organisms, if any are present, in the "Survey" (or "Once-over") column of the plankton counting sheet. If catch (a) is used, this large organisms count is really

(a) Microscopy of Drinking Water, Revision by Fair and Whipple, page 96.

the content of 20 cc of the original water. There may be a dozen organisms, or maybe only 3 or 4, or perhaps none at all.

(e) The plankton counting sheet recommended by Whipple, provides not only for this large organisms content, but also for a representative count of the smallest organisms, which are usually very much more numerous than the large ones. For this small organism count, either 5 or 10 fields are selected in representative positions of this counting cell, and the organisms in these fields are counted under a higher magnification, usually 16 mm. objective and 10 x ocular. This ocular is provided with a Whipple Ocular michrometer disk, and the tube-length of the microscope is adjusted by use of a stage michrometer so that the largest square on the disk exactly subtends 1 square millimeter on the stage. This square millimeter is the "field" to be counted, and since the counting cell is exactly 1 millimeter in depth, we are counting, on the floor of the cell, the organisms that represent 1 cubic millimeter of the catch from the original plankton sample. Five fields therefore represent 5/1000 or 1/200 of the contents of the counting cell, this cell being 20 millimeters by 50 millimeters and having an area of 1000 square millimeters. Ten fields counted represent 10/1000 or 1/100 of the contents of the counting cell, and so on, whatever numbers of fields may be counted. If, for instance, we have in the 5 representative fields counted:

(1) 20 of Organism A
10 " " B
15 " " C

we know that these totals are only 1/200 of what are actually in the entire cell, so multiplying by 200 we have:

(2) 4000 of Organism A
2000 " " B
3000 " " C

These largest numbers represent the actual total content of the counting cell.

Now, because this "catch" in the counting cell is a concentration, we must take this fact into consideration before we can state the result of our count in terms of the original sample of water. Since we concentrated the 100 cc sample to 5 cc (in the case of (a)) one cc of the concentrated "catch" must therefore contain the organisms content of 20 cc of the original water. In other words, the totals stated in (2) are twenty times as great as the actual content of the original water. To find this latter value, therefore, we divide these items by 20, with results as follows:

(3)	200 of Organism	A
	100 "	"	B
	150 "	"	C

For convenience, a formula involving the preceding relative values is often used. It is as follows:

$$\frac{\text{Cubic millimeters in 1 cc of the catch (in the cell)}}{\text{Cubic millimeters (fields) examined}} \times \frac{\text{cc of concentrated "catch" obtained}}{\text{cc of original sample of water used}} = \text{Factor}$$

Substituting values in the above formula:

$$\frac{1000}{5} \times \frac{5}{100} = \text{Factor } (= 10)$$

This "factor" is the number by which we must multiply our 5-field count data in order to express these values in terms of the actual content of the original water.

The Cover-glass Method: Lackey's method [(a)] of counting a definite portion of the catch by using several cover-slip mounts instead of the old-time counting cell has the unquestioned advantage of enabling the operator to switch instantly to the high power when the low power is found insufficient to identify the organism. Such occasions may be frequent, and the cover-glass method may be the preferable method, particularly if the large majority of the plankton organisms are very small. The large forms, however, should not be overlooked, although they

(a) Public Health Reports 53: No. 47, Nov. 25, 1938. Manipulation and Counting of River Plankton. By J. B. Lackey.

are usually few in comparison in many cases, - fewer than 1 per ml. (or cc.). Quantitatively considered, however, these few large organisms may nearly equal, or possibly overbalance, the larger numbers of very small organisms. One Rotifer tardus equals approximately 10 Codonella, or 80 Halteria, in volume. An ideal procedure would seem to be a combination of (1) the cover-glass method, because of its great advantage of identification by use of the high power, with (2) a rapid count, or inspection, of a larger quantity of the plankton catch either in a 1 cc counting cell or by inspecting, under low power, all of the area of at least 10 cover-slip mounts, which would be the equivalent of about one-half the 1 cc counting cell. This procedure would at once reveal the presence-or the absence-of the larger organisms and their relative abundance.

Lackey's cover-glass method (see (a)) is essentially as follows:

1. The centrifuged catch is mixed, and measured in terms of drops by using a pipette, so that 1 drop of catch bears a definite relationship to the amount of sample centrifuged. For example, if a 100 ml. sample, centrifuged, yields 76 drops of catch, enough of the decanted portion (in this case 24 drops) is added to make a total of 100 drops. This makes 1 drop of the catch equal 1 ml. of the original sample.

2. To count, place 1 drop of the catch on the center of a slide and cover with a No. 1 25 mm. cover glass (preferably square).

3. Using the low-power objective, count two paths entirely across the spread-out drop, one path horizontal, the other vertical, the two paths crossing at or near the center of the drop.

4. Repeat (3) with several other drops, perhaps ten or more, until the total or combined width of the twenty or more paths counted (2 paths per drop) is equivalent to the total diameter of the square cover-glass. In other words, the equivalent of 1 entire drop has been counted, and this completed count represents the organism content of 1 ml. of water of the original sample. In an unkilled catch, some of the organisms will quickly migrate to the edge of the cover-glass, seeking oxygen. Others will die, becoming motionless and perhaps difficult to detect. Still others will migrate toward the lighted edge or portion of the drop. By counting only two paths, then repeating this with a fresh mount, and

(a) Public Health Reports 53; No. 47, Nov. 25, 1938. Manipulation and Counting of River Plankton. By J. B. Lackey.

so on (see 4) the above difficulties are minimized or avoided. The low-power examination will not take into account some of the small but significant organisms. Hence the same procedure is followed with the high dry (10 or 12.5 x oculars, 40-45 x objective) combination, as with the low. However, one cover-glass comprises about 80 paths at a magnification of ca. 500 diameters, so only a few paths (6, 8 or 10) are counted instead of a whole drop. This makes it necessary to use a factor for estimating the numbers per ml. but if the procedure is constant, this factor and any error it introduces will be a constant. Furthermore, the entire catch from 100 ml. may usually be encompassed in 50 or even 25 drops.

5. The entire area of each drop may be quickly inspected with the low-power in order to note the possible presence of any large organisms, such as worms, rotifers and crustacea (b). If present in 10 ml. of the original water sample, they will usually show up in the examination of the <u>entire area</u> of such a number of one-drop cover-glass mounts of plankton catch as are required to represent 10 ml. of the original water. Large organisms as Paramecium, Aeolosoma or Rotifer may be counted by using 2 x or 5 x oculars with the 10 x objective, thus permitting a very quick examination of an entire drop.

D. Bottom Sediments

Pending acquisition of a suitable dredge by which quantitative areal samples of bottom mud may be secured, the old-time mushroom-shaped scoop, formerly used on the Potomac, the Ohio and the Illinois Rivers, may be used to secure a qualitative sample. This sample will furnish valuable information as to the make-up and the apparent sanitary status of the stream bottom, and the population of this mud (usually worms, mollusks, insect larvae and similar forms) will give further information along the same general lines.

The present plans call for one bottom sample per month from such locations as are thought to be representative. These locations will usually coincide with some of the plankton sampling stations, but may not be so numerous. Moreover, one point, instead of three (E. C. & W.) will usually be sufficient.

(b) See Public Health Reports, Nov. 18, 1938. Protozoan Plankton as Indicators of Pollution. J. B. Lackey.

This one point, at a given station, should be one where mud is available. It frequently happens that soft bottom (sediment) is available at only one of the E. C. & W. positions.

<u>Collection of Sediments</u> - See "<u>B - Bottom Sediments</u>"

<u>Laboratory procedure with the mud samples</u>

Equipment needed:

One.....2-liter mug-like dish, with stout handle (a 2-liter "Miner's cup" is ideal. Also half of a double-boiler is convenient).

Two or three. Moist chambers, large size (about 10 in. diameter)

One.....7-inch square of 25-30 mesh brass screen (or cloth) with corners well rounded off.

1 pair deep-jar forceps.

Proceed as follows:

1. Partly fill a moist chamber with clean water.

2. On the outside of the mason jar containing the mud sample, mark, with grease pencil, the upper level of the mud.

3. Empty the sample or part of it from the jar into the 2-liter "miner's cup" or other container. Record color, pastiness, odor, presence of pebbles, etc.

4. Introduce a partial fold extending from one side of the square of brass cloth, about to the center (not beyond) of this square. Press this partial fold over, and grasp the now dished screen with thumb and finger at this triangular area where there are now 3 thicknesses of the screen. Thoroughly wet this screen on both sides.

5. Run 100 cc or more tap water into the miner's cup or other vessel containing the mud sample. Agitate by a vigorous rotary motion and at once pour the suspension through the sieve or screen, which you are holding firmly with thumb and finger of the other hand.

6. Run more tap water into the container, agitate as before, and pour through sieve.

7. When some "screenings" have accumulated, invert the dished screen upon the surface of the clean water in the moist chamber, - slosh screen gently up and down, washing the catch from the now under side. It is convenient, at this point, to reverse the "dished" condition of the screen.

8. Proceed as in 5, 6 and 7 above, until all of the mud sample has been washed through the screen. Pebbles, sand, etc. will not wash through, and may be discarded after inspection by the biologist.

9. Run tap water into the jar to the grease-pencil mark (see 2). Measure this water. This is the amount of your mud sample. Record on your examination sheet this amount to the nearest multiple of 5, like 875 cc, 760 cc, 985 cc, 800 cc, etc.

10. Examine the catch in the moist chamber. Count or estimate the number of worms, mollusks, insect larvae, or other organisms. Note the presence of kinds of attached growths, such as fungi, algae, stalked ciliates, bryozoa, and the like. Inspect the catch for the presence of capsules, indicating the propagation of tubificid worms.

    Note any unusual abundance of detritus of any kind, such as leaf fragments, straw or chaff, bits of paper, fecal pellets of worms or insect, molts of insects, fibers apparently from a paper mill, saw dust, ect.

    If pebbles, or sand are present in considerable amount, the relative proportion of such material should be noted. For instance, a sample measuring a total of 850 cc may consist of about 200 cc of pebbles, 150 cc of sand and only 500 cc of actual mud. As a rule, these materials (pebbles and sand) need not be introduced into the moist chamber at all (see 8) but if present in considerable amount in the sample this approximate amount should be recorded.

11. <u>The record</u>

    a. Location, date and amount of sample.
    b. Color, condition and odor.

c. Predominance, or relative abundance of plant fragments, detritus, wastes, sand peebles, etc.

d. Population:

Worms (tubificid, naid, etc.)

Mollusks (bivalves and univalves)

Insect larvae (Chironomids, Mayflies, Caddis flies, etc.)

Attached forms such as bryozoa, stentors, stalked ciliates, etc.

Attached plant forms (diatoms fungi, algae)

Detached plant forms (algae, fungi, submerged plants of the higher types, etc.)

12. Final statement of population density should be in terms of 1 liter of sediment. For instance, if an 800 cc sample yields 2000 worms, this means 2500 in 1 liter.

Supplement to Memorandum No. 8

Points to be Covered in a Biological Survey of the Ohio River

1. Preliminary to the work, the map of the drainage area should be thoroughly studied. This will give an idea of the:

    Rapidity of run-off, which materially affects water age, hence biological productivity.

    Relative arable land conditions, materially affecting silt content of the water.

    Population density.

    General centers of industrial waste and their nature, e.g., mining areas, etc.

2. A determination should be made of the possible examinations. Since this cannot be determined by preliminary work, the following recommendations are made:

    A. Regular examination of plankton samples taken by collectors, and examined after centrifuging. Only those plankters should be counted which have been shown to be favorably or unfavorably affected by domestic sewage.

    It is recommended that 100 ml. of raw river water be taken from each composite sample, centrifuged 3 to 5 minutes at speeds between 2000 and 3000 r.p.m., the supernatant water decanted, and the catch measured, either as so many ml., or as so many drops, 1 ml. or 1 drop of catch having a definite ratio to the 100 ml. sample. If large plankters, as some of the larger Rotifera, are present in abundance, it is recommended that the catch be examined in a counting chamber, under a low-power binocular at 50 to 100 diameters. If such large organisms are few, it is recommended that an additional count be made by the drop method (previously published) and that the following species be counted:

Pollution-favoring	Clean-water favoring
Endorina elegans	Chroomonas - all species
Chlamydobotrys gracilis	Chrysococcus - all species
Pandorina morum	Cryptomonas erosa
Euglena gracilis	" ovata
" fusca	Cryptoglena pigra
Euglena oxyuris	Dinobryon - all species
" viridis	Domatomonas cylindrica
Lepocinclis texta	Euglena mutabilis
Anthophysa vegetans	" sciotiensis
Collodictyon triciliatum	" spirogyra
Carchesium spp.	Mallomonas caudata
Chilodonella uncinatus	Rhodomonas lacustris
Colpidium campylum	Synura uvella
" colpoda	Actinobolus radians
Colpoda cucullus	Codonella cratera
Colpoda aspera	Cyclidium spp.
Epistylis spp.	Strobilidium humile
Glaucoma scintillans	Strombidium spp.
" pyriformis	Tintinnidium fluviatile
Lionotus fasciola	Attheya zachariaci
Paramecium caudatum	Melosira granulata
Stentor polymorphus	Melosira varians
Vorticella spp.	Synedra biceps
	Actinastrum hantschii
	Ankistrodesmus falcotus

Other species occurring in large numbers should be counted if time allows, but may not be significant; Cyclotella, Chlamydomonas and possibly other species may occur in enormous numbers but not be significant. Hence, with lack of time, they can easily be preserved and possibly counted at another time.

B. The above plankton examination should reveal the sanitary condition of the water. But it should be supplemented by using a plankton net catch, which will include the crustacea and insect larvae which are not attached, also give a more accurate count of the large Rotifera, Nematoda, Gastrotricha, colonial protozoa and larger Algae and Desmids. This net catch should be made once weekly at the dams in the Ohio, but is not so important in the tributary streams. The catch should be preserved in 5% formalin, for eventual more careful examination.

C. Bottom dwelling forms. - See "<u>Laboratory procedure with mud samples.</u>"

D. It is recommended that traps holding glass slides suspended vertically be placed in the river at Cincinnati and at the Kiski to determine the rate of accumulation of attaching organisms. These can be examined at varying intervals.

E. Special examinations should be made of the plankton content, and also the bottom dwelling forms in tributaries to determine:

a. Contributions to main river.

b. Effects of specific trade wastes on those tributaries, as distillery wastes on Lawrenceburg Creek.

F. Isolated studies at various points during the course of the survey, to determine the immediate effect of industrial wastes, as a local effect. This would involve a survey above, one immediately below and one several miles (or hours flow) below the point at which the waste enters the stream.

3. A correlation of the important factors should be carefully sought as the survey progresses. For example, at times of low flow, the acid of the coal mining areas may travel far down the Ohio, but we as yet know nothing of its effects on life in the stream. Or a rain on the Licking may increase the turbidity of the Ohio greatly, without becoming an important diluting factor. But its effect on the plankton is to sharply decrease it.

Memorandum No. 9

June 7, 1939

Instructions Governing The Preparation Of Bacteriological Culture Media From Dehydrated Stock Powder

MEMORANDUM NO. 9

June 7, 1939.

INSTRUCTIONS GOVERNING THE PREPARATION OF BACTERIOLOGICAL CULTURE MEDIA FROM DEHYDRATED STOCK POWDER

It has been observed that difficulties have been encountered from time to time in the preparation of culture media from dehydrated products. These difficulties have been of two kinds - (1) Due to insufficient heating or to the formation of lumps when the dehydrated powder is added, the powder is not uniformly distributed when the mixture is prepared for sterilization. (2) Due to overheating or heating for too long a period, the finished media contains a precipitate which may be confusing. The contributing sources of error are extremely hard to detect when the media being prepared contains a dye.

Various types of preparatory methods have been tried out in detail and a procedure has been developed which (1) can be carried out rapidly, (2) avoids the difficulties referred to, and (3) produces a satisfactory, clear medium.

The instructions, which follow, are for a one liter portion of Standard nutrient agar. If larger amounts are to be prepared, the same instructions will apply multiplying the amounts given by the number of liters desired. The same instructions shall be applied to other varities of dehydrated media altering the amount of dehydrated powder employed per liter in accordance with the instructions given on the container.

Procedure for dissolving and preparing dehydrated Standard nutrient agar:

(1) Put 800 ml. of distilled water in pot or flask and apply heat.

(2) Weigh out 23.0 grams of dehydrated Standard nutrient agar, place in a beaker casserole or other suitable container and add 50. ml. of cold distilled water slowly. Mix well to a heavy paste, making sure that all of the powder is evenly wetted and free from lumps. When the water in (1) is boiling briskly, add an additional 150 ml. of cold distilled water to this paste and mix to give a free-flowing mixture.

(3) Add this concentrated agar suspension, (2), to the boiling distilled water, (1), stirring briskly and keeping the mixture boiling over a free flame. If the mixture has been prepared properly and is free from lumps, adequate solution of the agar will be obtained with 2 minutes (not to exceed 5) of boiling.

(4) Make up any loss in volume caused by evaporation.

(5) Distribute in containers in desired quantities and sterilize by autoclaving.

In the preparation with the apparatus available for use it may be found that the amount of cold water required for successfully carrying out step (2) may be decreased and the amount of boiling water in step (1) proportionately increased. If so this may be done for the smaller the volume of water used in (2) and the larger the amount in (1), the less the interference with the boiling temperature and the desired result will be obtained more quickly; providing always that a sufficien amount of cold water is used in (2) to obtain an evenly wetted, lump-free, free-flowing mixture.

Memorandum No.11

March 27, 1940

Information For Trailer Laboratory Crew

Memorandum No. 11

March 27, 1940

INFORMATION FOR TRAILER LABORATORY CREW

I - General

Operation of the mobile laboratory units has indicated that numerous problems and difficulties may arise not ordinarily encountered in the case of fixed laboratories with more ideal working conditions. This brief memorandum has been prepared with the idea of guiding the personnel of the units with respect to their duties and responsibilities.

On the basis of the work done in 1939 and in view of the decrease in number of tests to be made per sample in 1940, an average daily examination of eight (8) samples, 5 days per week, is contemplated. The length of the working day will necessarily vary in this type of field work. In another section of this memorandum the principal duties of each member of the party have been listed in the order of their importance and priority. By proper use of time and close cooperation by members of the unit, it is believed that the daily laboratory routine can be carried out in an eight hour day from Monday to Friday, 4 hours on Saturday, and a few hours, as necessary, on Sunday to examine samples under incubation. Modification of the sampling schedule may be necessary if the work cannot be completed in a 48 hour week. Occasionally it may be necessary for one or all members of the party to work longer hours than indicated above. If at all possible, without hindering the work, an equal time off shall be allowed for the extra time worked. The time off shall be taken within two weeks of the date the extra duty was performed and shall not be cumulative so as to add to the annual leave of the individual.

Change of location of trailer headquarters should be avoided on Sundays. However, Saturday moves should be made if sampling in a given area is completed by Friday of any week. Saturday is to be considered as a full working day of eight hours, according to the regulations of the U. S. Public Health Service.

The principal duties of the various members of the party are outlined below for the guidance of each member of the trailer personnel.

II - Duties of Personnel

Junior Chemist:

1) Supervise and direct the work of sample collector and laboratory attendance.

2) Program the work with the guidance and assistance of the engineers from the Stream Sanitation Office and the Stream Pollution Investigations Station.

3) Supervise and help in preparations for moving.

4) Supervise and help in making set-ups on new locations, making all contacts with local authorities personally, if at all possible.

5) Arrange with local authorities for use of any of their equipment or facilities - water, power, distilled water, etc.

6) Carry on analytical work with such assistance as laboratory attendant can give when he has carried out his primary duties as outlined below.

7) Complete laboratory records on analytical results with help of laboratory attendant, within one week of completion of work at a given set-up, and send cards and general report covering the work to Cincinnati headquarters.

8) Inform the Cincinnati office of all matters connected with payroll information and per diem - annual or sick leave of any member of party - time of leaving and arriving at various places with trailer, etc.

9) Send in on the last day of each month a tabulation showing: -

   A - Number of samples collected - (each regular collection at a sample point represents 4 samples - one is the bacteriological sample, one is the composite sample, and each D.O. bottle is a sample; four in all.

   B - Number of Bacteriological examinations for B. coli.

C - Number of Bacteriological examinations for total count.

D - Number of D. O. analyses made.

E - Number of B. O. D. Analyses made.

F - Number of Turbidity Determinations Made.

G - Number of pH " "

H - Number of Alkalinity " "

I - Number of Hardness " "

J - Number of Fe tests made

K - Number of Acidity Determinations made.

L - Number of Nitrite " "

M - Number of Any Special Determinations made.

Chauffeur:

1) Drive tow car and trailer unit from place to place and connect and disconnect tow car, etc., with help of other members of the party.

2) Sample collections.

3) Care of car and trailer, washing, grease & servicing, etc.

4) Help in making set-ups on new locations.

5) Call at post office for mail and express.

6) Ship cases, etc.

7) Help in dishwashing and laboratory work as instructed by Jr. Chemist to complete working day after all the above duties have been carried out.

Laboratory Attendant:

1) Prepare and sterilize media.

2) Wash and sterilize glassware.

3) Prepare laboratory reagents.

4) Help preparing for moving trailer and in making set-ups on new locations.

5) Assist Jr. Chemist in analytical work, as directed, when above duties have been completed.

6) Assist Jr. Chemist in completing records on the laboratory cards.

III - Proposed Schedulė of Laboratory Work

The routine tests contemplated are:-

1) Temperature.
2) Dissolved Oxygen - Azide Method.
3) 5-Day B. O. D.
4) Coliform Index - Dilution Method.

The following determinations shall be made occasionally as explained below: -

1) Alkalinity.
2) Turbidity.
3) Hardness (Soap Method).
4) Iron - (Total, Ferrous, Ferric).
5) Acidity to phenolphthalien (hot and cold).
6) pH.

Alkalinity shall be run on at least one sample from each sampling station. Turbidity and hardness shall be run on all samples at one station on each stream (preferably lowest point downstream). Iron, acidity and pH tests shall be made only on stream samples where acid mine drainage or other acid discharges result in pH values below 4.0, or where iron bearing wastes are present in appreciable amounts.

Methods to be followed in making these determinations shall be in accordance with Memorandum No. 4 on "Outline of Chemical Methods" and any supplemental instructions on specific procedures issued from the Cincinnati station. Where there is any doubt as to tests not covered in these references, the procedures in "Standard Methods" shall be used.

IV - Detailed Instructions

The actual time of reporting to work and leaving, lunch hour, etc., will vary with the duties of the individual. The sample collector will start his trips so as to be back with samples by 1:00 P. M. If it appears desirable, the Jr. Chemist and laboratory attendant may stagger their shifts. This arrangement indicated certain advantages during the work carried on in 1939.

Tow car shall be garaged at the trailer location (usually a water plant) if not located too far from the living quarters of sample collector so as to be within reasonable walking distance. If there are no facilities available at the water plant for car storage, or if too far from town, the tow car shall be garaged at a public garage and voucher obtained by the chauffeur for this expense. The tow car shall be used only for official purposes. The government shall not provide transportation for any member of the party between his living quarters and the trailer location. When trailer headquarters are changed, the chauffeur and laboratory attendant will use the tow car for their transportation. The Jr. Chemist will have travel authority allowing use of his car or of government transportation requests to take care of his transportation.

It may be necessary and desirable at times for the Jr. Chemist to make field trips to sampling points to carry on dissolved oxygen tests,etc., in order to properly locate certain sampling points. Whenever possible these trips shall be made either with the assistant public health engineer assigned to the trailers or in the government tow car. If either of these two methods of transportation are not available he shall use his private car and report the mileage traveled and all necessary information on the regular voucher form provided for this purpose. A statement explaining the necessity for the trip and work done shall accompany this voucher in order that travel orders can be prepared covering the particular travel or trip involved.

Purchases may be made for any reasonable item, and emergency repairs can be taken care of in the field. Vouchers for such expenditures should be obtained. If possible, government purchase orders shall be used for such expenditures.

The success of the mobile laboratories depends upon co-operation of all members and a good morale. These instructions are offered as a mechanical basis from which to work, but the success of the program depends upon each of the party members themselves.

Memorandum No.12

May 6, 1940.

Supplemental Chemical Procedures
For Upper Ohio River Samples

MEMORANDUM NO. 12

May 6, 1940.

SUPPLEMENTAL CHEMICAL PROCEDURES FOR UPPER OHIO RIVER SAMPLES

In the upper Ohio River and its tributaries acid iron bearing water will very likely be encountered. For this reason the following chemical tests and special procedures shall be followed to supplement and/or replace the procedures used in the middle Ohio River.

pH

The pH should be determined first either electrometrically or colorimetrically with an S.D.C. kit upon all samples. If the pH is 6.0 or above, total iron and one B.O.D. determination upon the water as received without pH adjustment or seeding should be made. But, if the pH of the sample is below 6.0, both total and ferrous iron and two B.O.D. determinations should be made. These B.O.D. determinations should be made as follows:

I. Upon one portion of the sample as received without pH adjustment or seeding.

II. Upon another portion following pH adjustment to 7.2 with N/10 Sodium Hydroxide and seeding with about 2.0% of normal river water (pH 6.8 to 8.0). The details of this procedure follow later.

Acidity

If the pH is below 6.0, the acidity to phenolpthalein of both hot and cold samples should be determined. When the pH is below 5.1 the phenolpthalein acidities and the acidity to methyl red should be determined. (See Standard Methods)

Iron

Total iron may be determined by boiling 50 ml. of sample with 5 ml. of 6 N nitric acid for 5 minutes, adding 3 drops of permanganate solution and cooling. Add 5 ml. of thiocyanate and compare immediately with standards prepared from standard iron solution with 6 N nitric acid. (Standard Methods p. 75) If the sample gives evidence of considerable pollution (is septic) the evaporation and ignition procedure of Standard Methods should be resorted to. (item 2.1 p. 74)

Ferrous Iron

Ferrous iron should be determined when the pH of the sample is less than 6.0 by the procedure given on page 76 of Standard Methods. As one part of ferrous iron results in an oxygen loss of 0.14 ppm in a neutral water and ferric iron increases the apparent oxygen content during the final acidification by the Winkler procedure, it is necessary to take the proper precautionary measures in determining dissolved oxygen in iron bearing waters.

Dissolved Oxygen

Because of the possibility of iron in the upper Ohio River and tributary water and the interference noted above, the Rideal Stewart procedure employing the introduction of 2 ml. of 40 per cent of KF. $2H_2O$ following the sulfuric acid and previous to the permanganate solution should be used for all dissolved oxygen determinations from new sources on the upper Ohio River system. If later experience upon water from any location consistently shows that samples have a pH above 6.0, are not septic and contain less than 10 ppm of total iron (under these conditions ferrous iron should not be present) the sodium azide modification for D.O. may be employed. However, it should be noted that the production of a faint straw-yellow color during the preliminary treatment with acid azide indicates the presence of considerable ferric iron. About 40 ppm of ferric iron can be detected by a faint color in a D.O. bottle. Larger quantities of iron increase the color intensity. Consequently the appearance of a straw or brown color during acid azide treatment indicates that the method is not applicable and that the use of potassium fluoride with the Rideal Stewart method the following important details of procedure must be carefully followed if dependable dissolved oxygen data are to be obtained. Follow the procedure outlined in Standard Methods item 2.1 page 147. Add 2 ml. of potassium fluoride and continue exactly through item 2.4. After the addition of the potassium oxalate the samples must be allowed to decolorize in the dark. The procedure should not be completed as soon as decolorization is apparently complete, but the samples should be allowed to stand for an additional 30 minutes in the dark before the manganous sulphate and alkaline potassium iodide are added. After shaking and settling twice, samples are ready to be acidified and titrated. If for any reason the samples cannot be titrated immediately, they should be allowed to stand in the alkaline state until they can be titrated. Then they should be acidified, one at a time, using 2 ml. of concentrated sulphuric acid in place of

the phosphoric acid suggested in Standard Methods, and titrated immediately.

B.O.D. Procedure II

The following B.O.D. procedure is to be applied as a supplementary test to the regular procedure where the pH of the sample is below 6.0. While a B.O.D. will be obtained in the pH range below 6.0, it is not due to the normal microflora and fauna. It is therefore necessary to make a pH adjustment to the normal biochemical range and reseed to obtain the normal B.O.D. A portion of the sample should be carefully adjusted with N/10 - NaOH until the pH is between 7.0 and 7.8. As this neutralization proceeds a heavy precipitate of ferric hydrozide may be obtained where much iron is present. When this occurs it is best to allow the precipitate to settle and check the pH on the supernatant. An attempt should be made to bring the pH to 7.2 but as long as pH 7.8 is not exceeded it is not necessary to readjust the pH with acid. After the pH has been adjusted, the sample should be seeded with 2.0% normal river water. If normal river water is not available, one ml. of domestic sewage filtered through paper (Whatman number 1) should be added per liter of sample. In either case the same concentration of seed used on the sample shall be put into dilution water and its B.O.D. determined so that a correction for seed can be made in the final B.O.D. calculations. In all cases where seeding is necessary, the B.O.D. obtained on the seed should be reported. The sample for B.O.D. should not be diluted until experience at the sampling point indicates that the dissolved oxygen will be depleted without dilution. In all cases where this supplemental B.O.D. after pH adjustment is made, the Rideal Stewart procedure employing potassium fluoride as described shall be used for all D. O. determinations.

A P P E N D I X   II

SPECIFICATIONS FOR MOBILE LABORATORY UNIT

APPENDIX II.

SPECIFICATIONS FOR MOBILE LABORATORY UNIT

1. SERVICE REQUIREMENTS

The trailer specified herein is for use by the United States Public Health Service as a mobile laboratory unit. It will be moved from place to place by the tractor unit which will be furnished by the Government and delivered f.o.b. the railroad station nearest the contractor's delivery point. The tractor unit shall be unloaded and serviced by the contractor, who shall make any alterations necessary for installation of towing irons on the tractor unit. The cost of unloading, servicing and alterations, if any, shall be included in the bid price. Installation of helper springs on the tractor unit shall be done by the trailer contractor.

The trailer and its tractor unit will travel to various parts of the United States over all kinds of roads and under various weather conditions which will necessitate unusually sturdy construction. Provision shall be made for adequate lighting, ventilation, plumbing, etc. as set forth in these specifications. Both plans and specifications form an integral part of the contract. Details described under specifications are equally binding as if shown on the plans and vice versa.

2. GENERAL DESCRIPTION

The unit shall be of the trailer type with a single rear axle equipped with single tires. The trailer shall be fully enclosed and provided with one side door near the front of the right side wall. Windows and door shall be installed as explained elsewhere in these specifications.

The trailer shall have the following minimum dimensions:

Inside length exclusive of nose section shall be not less than 15' 0".

Inside width exclusive of nose section shall be not less than 74".

Inside height exclusive of nose section shall be not less than 78"

Outside length overall, not less than 17' 2"

Outside width " " " " 78"

Outside height " " " " 99"

Bidders must state the exact dimensions of the trailer they propose to furnish.

The center line of the axle shall be so located as to provide a load space length along the floor of not less than 7 ft. 6" between the front edge of the front wheel housing and the front of the trailer at its widest width. Vertical load on draw bar for the trailer shell shall not exceed 300 lbs.

3. FRAME AND BRACING

The trailer shall be equipped with an all steel chassis running the entire length of the under structure, with secure anchorage at points of spring attachment and sidewall attachment. The sidewall structure shall be securely attached and braced to the underbody so that the outside sheeting material when applied will form a rigid shell. All sidewall structural members shall be securely fastened together by cadmium plated bolts or screws, to prevent rusting.

4. FLOOR, WALLS AND ROOF

The floor shall be made of double 5 ply floor paneling having a total thickness of one inch, and shall be covered by a good grade of linoleum at least 1/8 inch in thickness.

The outside walls from the lower rub rail to the roof rail shall be sheathed with 3/16" ply metal. This material shall consist of a sheet of rust proofed steel glued with a suitable water proofed bond to plywood built up in similar fashion.

The curved roof bows shall be made of thoroughly seasoned spruce or equal placed close enough together and braced longitudinally so as to form a rigid roof construction. The roof bows shall be covered with 3-ply fir or equal plywood not less than 3/16" in thickness, painted with an asphaltic paint and then covered with No. 10 extra heavy waterproof canvas, treate

with aluminum paint, suitable for outside exposure.

The interior side walls and ceiling shall be covered with 3-ply fir or equal plywood not less than 3/16" in thickness and of kiln dried, low moisture content, stock. Space between inside and outside linings of roof and side walls shall be insulated against heat by a combination of not less than 1-1/2" of dead air space filled with approved insulation such as spun glass or equal. Floor and wheel housings shall be insulated with celotex and padding.

5. AXLES, WHEELS, TIRES

The axle shall be of a suitable alloy steel forged in one piece and equipped with the necessary hubs for the installation of wheel equipment. The axle capacity shall be ample to carry the load of trailer shell and a payload of 2,000 lbs. The unit shall be equipped with suitable, 12 leaf springs constructed of a high grade of silicon manganese steel. The wheels shall be constructed of pressed steel of the closed disk type, with chrome-plated hubs, and the outward appearance of same shall be in close conformity with the exterior appearance of the trailer unit. The tires furnished shall be of the proper size to accommodate the total weight of the trailer and equipment (payload 2,000 lbs.) and shall be rated in accordance with the latest tire and rim association standards.

Spare tire, tube, and rim or wheel shall be provided and suitably mounted at the rear of the trailer unit. The tire carrier shall be equipped with a suitable locking device, complete with two keys. Tools for making a tire change shall be furnished.

6. WINDOWS, DOORS, AND VENTILATORS

The trailer shall have eight windows located as shown on the plans, and of the sizes indicated there. The windows shall be of the drop type and all glass in the trailer shall be shatterproof glass. The trailer door shall have a window as shown on plans. A folding screen door shall be installed at the trailer doorway. Screen door, all drop windows, and ventilator opening shall be provided with removable 16 mesh copper screens. Each window shall be provided with a good grade roll shade of color to harmonize with the trailer color.

Roof ventilator opening shall be located as shown on plans with hinged hatch that may be opened to desired height from

inside the trailer. An electric ventilating fan, with capacity of 200 cu. ft. of air per minute shall be provided and installed preferably in the roof ventilator space. Roof ventilator shall be built above the outer roof level if necessary to accommodate the fan. The fan unit shall not extend into the trailer below the inside ceiling surface. The fan shall operate satisfactorily on either 110 volt, 60 cycle, single phase alternating current or on 110 volt direct current. A switch to control the fan operation shall be provided.

7. BRAKES

The trailer shall be equipped with Warner Electric Brakes, or equal, having heavy duty brake linings, and with a Warner Brake Control Kit, or equal. The brakes shall be installed with all accessories and attachments, complete and ready for use. An adequate safety brake shall be furnished for locking the trailer wheels in case of emergency and for parking.

8. ELECTRICAL

(a) Lights - 6 volt system.

The trailer shall be equipped with outside running lights to conform with Interstate Commerce Regulations and in addition equipped with combination "turn" signal and stop and tail lights. All of these lights and a central dome light in the trailer shall be connected to the tractor car through a convenient connector and operate with the tractor car light switch.

(b) Wiring and General (110 volt electrical current; may be either direct or alternating).

All wiring electrical work and fixtures shall meet the requirements of the National Electrical Code.

Opening on the outside of the trailers, flush with the finished surface, there shall be installed a weather and dust proof electrical receptacle through which the trailer shall be supplied with electrical current from an outside source. The 110 volt electrical current shall be supplied to the trailer from an outside source by plugging in the 150 foot electrical cable specified elsewhere. The outside receptacle shall be wired to a "Nofuze Load Center" located in the interior of the trailer at a convenient and accessible point. It shall also be located within one or two feet of the outside receptacle.

The load center shall be of the type made by either Graybar Electric Company or Westinghouse Company; the most compact unit available shall be selected. This load center shall have four single pole circuits. Three shall be of 15 amperes capacity each, and the fourth of 20 ampere capacity, The 15 ampere circuits shall be wired to the following units:

(1) Seven 110 volt ceiling and wall lights, and ventilating fan,

(2) The two double wall receptacles on one side of the trailer,

(3) The two double wall receptacles on opposite side of trailer.

The 20 ampere circuit shall be wired to a double base receptacle located at the base of the trailer near the door, as shown on the drawings.

Four double electrical wall receptacles shall be installed as shown on drawings.

Interior lighting shall be provided by seven light fixtures located as indicated on the drawings. These fixtures shall be firmly fastened to the trailer shell and shall be of a type with bulb setting in a horizontal position and having an adjustable cylindrical shade or reflector with bronze finish on the exterior and aluminum paint finish on the interior reflecting surface. Each fixture shall be an individual pull chain switch, and all seven shall be controlled by a single switch located at the side of the trailer door.

The contractor shall furnish 150 ft. of stranded electrical cord insulated with heavy live rubber, weather proofed, with plugs and attachments which shall carry the current from an outside source to the receptacle at the trailer. This cord or cable shall be of ample capacity to supply safely the current required to operate the present and future load which will be a total of 4500 watts.

The attachment plug on one end of the cable shall fit into the receptacle provided in the front end of the trailer. The other end of the cable shall be fitted with a substantial two-pronged plug (with parallel prongs), for tapping into a standard 110 volt wall receptacle.

The dome light, shown on drawing, (with independent switch at side of door) tail lights and side clearance lights shall operate on 6 volt direct current from tractor car power system. Wiring and connections shall be installed independently of the 110 volt system. An outside receptacle shall be installed at the front end of the trailer for connection of the 6 volt trailer circuit to the tow car circuit. A connecting cable shall be supplied for use with a standard Ford, Chevrolet or Plymouth coupe as tractor car, and the trailer system shall be controlled by the tractor car light switch.

9. WATER SUPPLY

At the rear end of the trailer under rear sink, a 30 gallon water storage tank shall be installed as indicated on the plans. The tank shall be made of rust resistant materials and shall have two baffle plates built into it to minimize water motion and swaying. The tank shall have an outside spout for filling, and a drain plug in the bottom for draining it, accessible from the outside.

In addition to the tank water supply, provision shall be made at the rear of the trailer for a 3/4" hose connection to city pressure. On the outside this hose receptacle shall be equipped with a chrome plated cap attached to the trailer with a chain. From the inside, a copper tubing connection shall be made to a goose neck spigot. This fixture shall be installed at the sink at rear of the trailer. The piping, gooseneck spigot and hose receptacle shall be provided and installed by the trailer contractor. This system shall be designed to operate without leaks or trouble at a pressure of 150 lbs. per sq. inch.

All copper tubing used for water supply lines to faucets and tanks shall be housed and protected by wooden framing wherever they pass through cupboards or lockers.

10. INTERIOR FURNITURE AND EQUIPMENT

(a) Front and rear lockers.

Rear cove locker and front end closet and lockers shall be built in as indicated on the plans. These units shall be made of plywood and shelves shall be installed

as indicated.

A 5-1/2" shelf with cleat 1/4" thick, and rising 1/2" above top of shelf level on ends and front edge, shall be installed as shown on plans.

(b) Laboratory Benches.

The laboratory benches indicated on plans shall be built into the trailer. Drawers, cupboards, and open spaces beneath bench tops shall be provided as shown on plans. All drawers and cupboard doors shall have adequate fasteners installed so they will remain shut during movement of trailer without the necessity of locking them. This furniture may be constructed of plywood of suitable thickness except the bench tops. These shall be made of one inch clear douglas fir or equal, and shall have dowelled and glued joints so as to prevent opening of cracks. The bench tops shall be left unpainted but doors, drawers, etc. shall be stained a light oak color, and varnished to match interior wall finish of trailer. (Bench tops will be treated with acid proof paint by the U. S. Public Health Service after delivery of trailers.) There shall be at least 36" clearance from under surface of bench tops to the floor. If possible, so as not to extend benches above window sill, this clearance shall be 38".

The doors of the cupboard over the wheel housing shall have a clear opening 8" x 10" in size. This opening shall be covered by a 4 mesh brass screen neatly fastened to the doors from the inside. An opening 5" x 10" in size shall be provided in the wheel housing in this cupboard as shown on the drawings. This opening shall be screened with an 8 mesh brass screen. A hinged cover with a latch shall be placed over this opening inside the cupboard. The opening is to be used for providing ventilation to the 20° incubator compressor unit which is to be installed in this cupboard.

(c) Ice Box Unit.

Over the wheel housing opposite the door, an ice box and sink unit of standard trailer design shall be installed - plans indicate exact location. This unit shall have a 12" x 18" porcelain sink with drain and stop. A double action water pump shall be installed at this sink with copper suction line to water storage tank at rear of trailer.

The ice box shall be provided with an ice compartment having a capacity of not less than 40 lbs. of ice. The food compartment shall have one shelf at mid-height of the storage space. An outside drain from the ice compartment shall be provided. Ice and food compartment shall be made of rust resistant materials.

(d) Rear Bench, Sink and Covering.

In the bench at the rear of the trailer a sink and lead covering on bench shall be installed. The sink shall be located as indicated on the plans and shall be similar and equal to that made by Kewaunee Manufacturing Company, Adrian, Michigan, and shown on p. 35 of their 1935 catalog, as sink No. S-755. This is a Karcite sink with dimensions as follow:

	Length	Width	Depth
Inside	22"	14"	6"
Outside	24½"	16½"	7-1/8"

The top of the sink cabinet and adjoining bench, as indicated on plans, shall be covered with sheet lead consisting of Tellurium lead weighing not less than 4 lbs. to the square foot and shall be sloped to drain into the sink. All joints shall be burned with pure lead. This lead sheet shall extend over the curb and into the sink opening. A raised bead shall be formed 1/4" high around all four edges of the sink bench and drainboard, to prevent spilled acids from dripping onto the floor. This bench top shall have a drip groove in the under side of the top at the outer edges and around sink opening to prevent capillary attraction carrying water into the case work. No solder shall be used in making any of the joints. Sink drain shall be of extra heavy tellurium lead, and all joints shall be burned with pure lead. No solder shall be used. The sink drain shall discharge to the ground and be convenient of access for connection of a hose when necessary or desirable to lead sink drainage to a sewer. A double action suction pump shall be installed at the rear sink, as shown on plans, with connection to the underside of water tank for delivering water to the sink. As noted under "Water Supply," this sink shall also have a goose neck spigot fixture to be supplied by city water pressure.

11. MISCELLANEOUS

Trailer contractor shall supply a two burner gasoline stove. This shall be a Coleman 2 burner stove #392, or equal.

The trailer contractor shall supply two one quart size Pyrene Fire extinguishers or equal. with necessary wall clamps.

A trailer jack shall be provided by trailer contractor with a caster wheel, raising and lowering on a worm thread acting as a jack, to raise or lower front end of the trailer.

A pair of heavy duty passenger car type tire chains of the proper size for the trailer tires shall be furnished by the trailer contractor.

The trailer contractor shall furnish four stabilizing jacks of ample strength to steady the trailer unit against movement when it is set up for laboratory use. The following jacks or equal will be acceptable:- "E-3 Jack Twins" manufactured by Wiedman Specialty Company, 20 Clinton Street, Tonawanda, New York.

Drawbar, Coupler, and Tow Iron

Trailer contractor shall install draw bar equipment, firmly anchored to trailer underbody, as part of trailer contract. This draw bar shall be fitted with a ball and socket type of coupler, which shall be of ample strength to transfer trailer load to tractor unit. Safety chain shall also be supplied to augment this draw-bar coupling.

A vent opening with vent pipe, flashing and hood, installed, shall be provided. The vent shall not extend into the interior of the trailer but shall be capped temporarily. This vent unit is to be provided for future use as a stove vent. It shall be installed in the position indicated on the plans.

12. TRACTOR UNIT

The tractor unit shall be a new coupe automobile furnished by the Government and delivered to the trailer contractor's plant. The trailer contractor shall make any necessary alterations to accommodate the trailer coupling device, the cost of alterations to be included in his bid price. The trailer car contractor shall make all necessary electrical, brake and draw bar connections. The tractor unit shall be equipped by the trailer car contractor with the necessary iron bar by which the trailer shall be drawn. This bar shall be attached rigidly to at least two cross frame members of the tow car frame. It shall be of ample strength to support safely a draw bar load of 600 lbs. Helper springs shall be installed on the tractor car by the trailer contractor, and shall adequately reinforce the rear springs of the tractor car for the load to be carried.

It shall be permissible for the trailer contractor to drive the tractor car under its own power provided:-

(1) The helper springs, iron tow bar, etc. cannot be installed at the contractor's plant, and

(2) That the total distance traveled for having such installations made shall not exceed 50 miles.

13. UNITS TO BE SUPPLIED BY CONTRACTOR

Trailer contractor shall furnish trailer built to conform to these specifications and shall include all furniture such as cabinets, cupboards, drawers, ice box and sink unit, capped vent opening for stove, water tank and necessary piping for both sink faucets, electrical wiring and receptacles, nofuze load center, 150' of electrical connecting cable, a 2 burner gasoline stove, 2 one-quart fire extinguishers, ventilating fan, tire chains and trailer jacks, all as specified.

14. UNITS TO BE SUPPLIED BY U. S. PUBLIC HEALTH SERVICE (To be installed by U. S. Public Health Service after delivery of trailer)

1 autoclave,
1 20° C. Incubator,
1 37° C. Incubator,
1 Hot Air Sterilizer,
1 Electric Hot Plate,

15. COLOR AND LETTERING

The exterior finish shall be high-grade, automotive gray enamel. Exterior shall be painted gray and shall receive one primer coat, two color coats and one finishing coat. Within one week of award of the contract the successful bidder shall provide a sample color plate of the finished trailer color to the Government in order that it may be forwarded to the tractor car contractor for the purpose of matching the colors of the two units.

The words:- Federal Security Agency
U. S. Public Health Service
Official

shall be placed in gold leaf letters with black outlines on each side of the trailer. They shall be placed on the door of the trailer on one side and directly opposite on the other. The words "Federal Security Agency" shall be in letters 7/8" high; the words "U. S. Public Health Service" shall be in letters 1¼" high, and the word "Official" shall be in letters 5/8" high. All lettering shall be painted over with two coats of durable outside spar varnish.

16. INSPECTION AND DELIVERY

After all the connections have been made to the tractor unit, a representative of the Government will inspect the trailers, tractor cars and connections. At that time, if everything is satisfactory, the entire train shall be turned over to this inspector or shipped on Government Bill of Lading to the United States Public Health Service, Cincinnati, Ohio.

Due to the urgency of obtaining these units the bidder shall state the time in which delivery can be made. This delivery time will be duly considered in making the award of contract.

A P P E N D I X III

LABORATORY FORMS

LABORATORY FORMS

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TREASURY DEPARTMENT
U. S. PUBLIC HEALTH SERVICE
Form 9125—March 22, 1926

STREAM POLLUTION INVESTIGATIONS

BACTERIOLOGICAL DATA

.... At .... Sample No. ....

From Section .... Temperature ....°C.

Date Collected .... hr. .... Date Examined .... hr. ....

pH. .... Alkalinity .... p. p. m. Turbidity .... p. p. m.

TOTAL COLONIES PER C. C. GROWING ON

AMT. C. C.	GELATIN, 20°C., 48 HRS.	AGAR, 20°C., 48 HRS.	AMT. C. C.	AGAR, 37°C., 24 HRS.	
AVERAGE:			AVERAGE:		

COLI-AEROGENES GROUP DETERMINATIONS

LACTOSE BROTH			CONFIRMATION; PLATES, BROTH, STAIN AND METHYL RED TEST										
AMT. C. C.	(A) FIRST BROTH TUBE		(A) ENDO PLATE		(B) TUBE FROM (A) ENDO		(B) Endo FROM (B) TUBE		AFTER 48 HR. 37°C				
	Gas		Appearance		Gas		Appearance		Agar Slant			D. P. P. Broth	
	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	Gram	Pure	Spore	M. R.	V. P.

Number of Coli-Aerogenes Group per .... c. c. .... Type ....

2—13909
GOVERNMENT PRINTING OFFICE

Form No. 2

UNITED STATES PUBLIC HEALTH SERVICE

OXYGEN DEMAND AT 20° C.

Source of Sample ....

.... *Date* ...., *19*.....

SAMPLE	DAYS INCUBATED	PER CENT CONCENTRATION	BURETTE READING C. C.		DISSOLVED OXYGEN P. P. M.				OXYGEN DEMAND
			INITIAL	FINAL	INITIAL	FINAL	DEPLETION		
							ACTUAL	COR.	

Form 9437—Federal Security Agency—Public Health Service—Oct. 1939 GPO 16—12871

Form No. 3

U. S. PUBLIC HEALTH SERVICE
OHIO RIVER POLLUTION SURVEY

Chemical Data

Laboratory ____________ Date ________________ 19__

SAMPLE NO.	SOURCE OR STATION NO.	pH	Turbidity	ALKALINITY DET. ON 100 ml. PORTION		DISSOLVED OXYGEN	
				Burette Reading	Alka p.p.m.	Method Used	Burette Readings ml.

ACID STREAM WATER OXYGEN DEMAND AT 20° C.

Source of Sample ____________________

Sample No. ____________________ Date ____________________

Sample Incubated as Collected

Ferrous Iron	Initial	Final	Loss During Incubation
Sample ml.			
Standard Matched			
Titre - P.P.M.			

B. O. D. (D. O. method used ____________________)

Days Incubated	% Concentration	Burette Reading ml.		Dissolved Oxygen P.P.M.				Oxygen Demand
		Initial	Final	Initial	Final	Depletion		
						Actual	Cor.	

Sample Incubated after pH adjustment and innoculation

Initial pH ____ pH after adjustment ____ Seed used ____________

Days Incubated	% Concentration	Burette Reading ml.		Dissolved Oxygen P.P.M.				Oxygen Demand
		Initial	Final	Initial	Final	Depletion		
						Actual	Cor.	

Form No. 5.

U. S. Public Health Service - Ohio River Pollution Survey

ACID STREAM WATER CHEMICAL DATA

Laboratory________________ Date________________

Source________________ Sample No.________________

pH____________ Turbidity____________ Color____________

ALKALINITY			HARDNESS		
Sample ml.	Bur.Reading	P.P.M.	Samp. ml.	Bur. Read.	P.P.M.

ACIDITY

Method	Sample ml.	Burette Readings	P.P.M.
Methyl Red			
Phenolph-thalcin Hot			
Phenolph-thalein Cold			

TOTAL IRON

Sample Ml.	Standard Matched or Burette Readings	P.P.M. Iron

U. S. Public Health Service - Ohio River Pollution Survey

ACID MINE WATER CHEMICAL DATA

Sample____________________________ Source____________________

pH_______________________ Sulphate__________________p.p.m.

ALKALINITY

Method	Sample-ml	Readings	Alkalinity p.p.m. as $CaCO_3$
Methyl Red			
Methyl Orange			

ACIDITY

Method	Sample ml	Burette Readings	Acidity p.p.m.as $CaCO_3$	Electrometric pH at "E. P."
Methyl Red				
Phth. Hot				
Phth. Cold				

TOTAL IRON

Sample-ml	Standard Matched or Burette Reading	p.p.m. Iron

(1) R_2O_3_____________________p.p.m. (2) R_2O_3- 1.43 Fe___p.p.m.

(3) (A-1) 0.529 (2)_______________p.p.m.

U. S. Public Health Service - Ohio River Pollution Survey

ANALYSIS OF RIVER MUDS

Sample #__________ From__________

Date Sampled__________ Date Received__________

Condition__________ Odor__________

Appearance__________

Det. of Moisture and Volatile Solids

(1) Tare + Sample__________ Moisture $\frac{(1) - (2) \times 100}{(1) - (4)}$ = __________%

(2) Tare + Dry Mud__________

(3) Tare + Ash__________ Vol. Matter $\frac{(2) - (3) \times 10^6}{(2) - (4)}$ = __________ppm.

(4) Tare__________

Oxygen Consumed Data

(8) Sample__________grams "Apparent Immediate Demand"

(9) C.C.$K_2Cr_2O_7$______ (10)C.C.$FeSO_4$______ Dilution__________

$\frac{(9) - (10)}{(8)\ (M/100)} \times F_2$ = __________ppm D.O.Differential (D)__________

"A.I.D."= $\frac{D \times \text{Dilution Factor}}{(M/100)}$

Organic Nitrogen

(11) Sample __________grams

(12) __________ C.C.__________ N Acid (13)__________C.C.__________N alkali

Nitrogen - $\frac{(12) - (13)}{(11)\ M/100} \times F_3\ F_4$ = __________% Nitrogen

B. O. D. - Data

Days	B. O. D. ppm (Dry)
1	
3	
5	
7	
9	
___	

Grit______ %__________

Remarks__________

Form No. 8

U. S. Public Health Service - Ohio River Pollution Survey

BIOLOGICAL EXAMINATION

Watershed ______________________ Mileage ______________________

Subwatershed ______________________ Mileage ______________________

Station	1	2	3	4	5	6	7	8	9	10	11	12
Location												
Mileage												
Date												
Agar Count												
B.O.D.												
D.O.												
pH												
Plankton (No. per cc.)												
Algae												
Chrysophyceae												
Chromulina sp.												
Chrysococcus rufescens												
" major												
" ovalis												
" asper												
Mallomonas caudata												
" sp.												
Hymenomonas roseola												
Synura uvella												
Dinobryon sertularia												
Lagynion Scherffelii												
Total												
Cryptophyceae												
Rhodomonas lacustris												
Chroomonas spp.												
Cryptomonas erosa												
" ovata												
Total												
Euglenophyceae												
Euglena viridis												
" pisciformis												
" sanguinea												
" variabilis												
" Ehrenbergii												
" acus												
" oxyuris												
" torta												
" tripteris												
" deses												
" polymorpha												
" gracilis												

Station	1	2	3	4	5	6	7	8	8	10	11	12
Lepocinclis ovum												
" texta												
Phacus longicauda												
" anacoelus												
" pleuronectes												
" triquerter												
" pyrum												
Trachelomonas volvocina												
" crebea												
" hispida												
" urceolata												
Cryptoglena pigra												
Peranema sp.												
Petalomonas mediocanellata												
" carinata												
Total												
Chlorophyceae												
Mesostigma viride												
" grarde												
Heteromastix angulata												
Chlamydomonas spp.												
Chlorogonium sp.												
Sphaerellopsis fluviatilis												
Thorakomonas sp.												
Wislouchiella planctonica												
Labomonas rostrata												
Coccomonas orbicularis												
Phacotus lenticularis												
Pteromonas aculeata												
" cruciata												
Polytoma uvella												
Gonium pectorale												
" sociale												
Pandorina morum												
Eudorina elegans												
Total												

Station	1	2	3	4	5	6	7	8	9	10	11	12
Diatomeae												
Synedra acus												
" radians												
" biceps												
" ulna												
Cyclotella spp.												
Navicula spp.												
Asterionella formosa												
Melosira												
Gomphonema												
Nitzschii												
Total												
Miscellaneous												
Actinoastrum												
Anabaena												
Ankistrodesmus sp.												
Botryococcus												
Chroococcus												
Closterium												
Coelastrum												
Cosmarium												
Crucigenia												
Dictyosphaerium												
Golenkinia												
Merismopedia												
Microcystis												
Oocystis												
Oscillatoria												
Pediastrum												
Kirchneriella												
Scendesmus sp.												
Sorastrum												
Staurastrum sp.												
Total												
Protozoa												
Amoeba												
Codomonas annulata												
Oicomonas sp.												
Domatomonas cylindrica												
Bodo sp.												
Cladomonas sp.												
Vorticella sp.												
Podophrya												
Codonella cratera												
Prorodon sp.												
Colpodium Colpoda												
Urotrichia farcta												

Station	1	2	3	4	5	6	7	8	9	10	11	12
Tintinnidium fluviatile												
Collodictyon triciliatum												
Glaucoma scintillans												
Lionotus												
Cyclidium sp.												
Actinophrys sol.												
Strobilidium humile												
Strombidium												
Total												
Dinoflagellata												
Rotifers and Crustaceans												

Form No. 9.

U. S. Public Health Service - Ohio River Pollution Survey

ROUTINE ANALYSES

Laboratory_______________ Month of__________ 19____ Compiled by_______________

Sample No.							
Stream							
Station							
Place							
Point							
Date							
Time Sampled							
River Stage-Gage Ht.(Ft.)							
River Disch.(Thous.sec.Ft.)							
WATER TEMPERATURE °C.		Right					
		Center					
		Left					
		Average					
DISSOLVED OXYGEN	p.p.m.	Right					
		Center					
		Left					
		Average					
	% Sat.	Right					
		Center					
		Left					
		Average					
5 Day B.O.D. Comp. or Ave.							
COLIFORM GROUP Most Probable No. Per ml.		Right					
		Center					
		Left					
		Average					
CHEMICAL TESTS		pH					
	Parts per Million	Turbidity					
		Alkalinity					
		Acidity					
		Hardness					
		Iron					

Form No. 10.

U. S. Public Health Service - Ohio River Pollution Survey

ACID STREAM WATER ANALYSES

Stream ______________________

Station ______________________ Laboratory ______________________

Place ______________________ Compiled By: ______________________

Point ______________

								Average
Sample No.								
No. of Days Sampled								
River Disch. (Thousands of sec. ft.)								
pH								
Alkalinity (M.O.) p.p.m.								
A C I D I T Y As $CaCO_3$ p.p.m.	Phenolph-thalein Hot							
	Phenolph-thalein Cold							
	Methyl Red							
I R O N (ppm)	T O T A L							
Ferrous	Initial							
	Final							
	Loss during Incubation							
5 Day B.O.D. (ppm) Acid Sample	Observed							
	Oxygen equiv. of loss in ferrous iron							
	Corrected B.O.D.							
Neutral Sample	Observed							
	Notes							

Remarks:

Form No. 11.

U. S. Public Health Service - Ohio River Pollution Survey

RIVER MUD ANALYSES

Sample No.						
Source						
River Stage						
Date Collected						
Date Received						
Condition						
Odor						
Appearance						
Per Cent Grit (By Volume)						
Per Cent Moisture						
Volatile Matter p.p.m. (Dry Basis)						
Organic Nitrogen p.p.m. (Dry Basis)						
Oxygen Consumed p.p.m. (Dry Basis)						
Apparent Immediate Demand (p.p.m.) (Dry Basis)						
B. O. D. p.p.m. (Dry Basis)	1 day					
	3 days					
	5 "					
	7 "					
	9 "					
Value of K						

RESULTS BELOW EXPRESSED AS ORGANIC NITROGEN, OXYGEN CONSUMED, 5-DAY B.O.D., PER PPM OF VOLATILE MATTER

Organic Nitrogen					
Oxygen Consumed					
5-Day B. O. D.					

Remarks:

WORK SUMMARY - AVERAGE RESULTS

Laboratory________ Month of________ 19____ Compiled by________

STATION	DAYS SAMPLED	RIVER STAGE Gage Height in Feet	RIVER DISCHARGE Thousand Sec.Ft.	WATER TEMPERATURE °C.				DISSOLVED OXYGEN								5-DAY B.O.D. p.p.m.	AGAR COUNT Per ml 24 Hrs. 37°C.	COLI-AEROGENES GROUP		CHEMICAL DETERMINATIONS					
								Parts Per Million				Per Cent Saturation								pH	Results in p.p.m.				
																								Suspended Solids	
				R.	C.	L.	Ave.	R.	C.	L.	Ave.	R.	C.	L.	Ave.			Dilution Method M.P.N./ml.	Direct Count Per ml.		Nitrites	Turbidity	Alkalinity	Total	Vol.

United States Public Health Service - Ohio River Pollution Survey

Form No. 13.

WORK SUMMARY - AVERAGE ACID STREAM RESULTS

Laboratory__________ Month of__________ 19_____ Compiled by__________

STATION	DAYS SAMPLED	RIVER DISCHARGE Thousands of Second ft.	pH	ALKALINITY to Methyl Orange as $CaCO_3$ (p.p.m.)	ACIDITY as $CaCO_3$ (p.p.m.)			IRON (p.p.m.)				5 DAY B. O. D. (p.p.m.)				
					Phenolphthalien				Ferrous			Acid Sample			Neutralized Sample	
					Hot	Cold	Methyl Red	Total	Initial	Final	Loss During Inc.	Observed B. O. D.	Ox.Equiv. of loss in Ferrous Iron	Corrected B. O. D.	Observed B. O. D.	Notes

TABLE.......

OHIO RIVER POLLUTION SURVEY
LABORATORY DATA

SOURCE OF DATA:

Trailer Laboratory ....

Cincinnati Laboratory ....

Laboratory Boat Kiski ....

............................WATERSHED

SUMMARY OF INDIVIDUAL RESULTS

Sampling Point	Mileage From Mouth	Date 1940	Average Discharge c. f. s.	Temp. °C.	Dissolved Oxygen p. p. m.	Dissolved Oxygen % Sat.	5 Day B. O. D. p. p. m.	Coliforms M. P. N. Per ml.	pH	Turbidity p. p. m.	Alkalinity p. p. m.	Hardness p. p. m.

Form No. 15

TABLE........

OHIO RIVER POLLUTION SURVEY
LABORATORY DATA

SOURCE OF DATA:

Trailer Laboratory ....

Cincinnati Laboratory ....

Laboratory Boat Kiski ....

..............................WATERSHED

SUMMARY OF AVERAGES

Sampling Point	Mileage From Mouth	Period	Number of Samples	Average Discharge c. f. s.	Temp. °C.	D. O. p. p. m.	5 Day B. O. D. p. p. m.	Coliforms M. P. N. Per ml.	pH	Turbidity p. p. m.	Alkalinity p. p. m.	Hardness p. p. m.

Form No. 16.

Table -7A ____________ River Basin

U. S. Public Health Service - Ohio River Pollution Survey

SUMMARY OF ACID STREAM RESULTS

Stream	Sampling Point	Date	No. Samples	pH	ACIDITY P.P.M.			IRON P.P.M.	
					Methyl Red	Phenolphthalein Hot	Phenolphthalein Cold	Ferrous	Total

OHIO RIVER POLLUTION SURVEY

FINAL REPORT
TO THE
OHIO RIVER COMMITTEE

SUPPLEMENT "C"

ACID MINE DRAINAGE STUDIES

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
CINCINNATI, OHIO
1942

ACID MINE DRAINAGE STUDIES

Supplement "C" to
Final Report to the Ohio River Committee
Ohio River Pollution Survey

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
CINCINNATI, OHIO
1942

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Fig. Ac-1


OHIO BASIN
COAL FIELDS
Fig.-3
LEGEND
Anthracitic
Low volatile bituminous
Medium high volatile bituminous
Data from U.S. Geological Survey
0 25 50 75
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
MARCH 1941
LAKE ERIE
ILLINOIS
INDIANA
OHIO
PENNA.
N. Y.
MD.
W. VA.
VIRGINIA
KENTUCKY
TENNESSEE
N. C.
S. C.
GEORGIA
ALA.
MISS.
MO.
CHICAGO
SOUTH BEND
TOLEDO
CLEVELAND
AKRON
YOUNGSTOWN
CANTON
PITTSBURGH
FORT WAYNE
COLUMBUS
DAYTON
CINCINNATI
INDIANAPOLIS
LOUISVILLE
EVANSVILLE
ST. LOUIS
NASHVILLE
KNOXVILLE
CHATTANOOGA
BALTIMORE
WASHINGTON
RICHMOND
Erie
Jamestown
Oil City
Altoona
Harrisburg
Johnstown
Wheeling
Cumberland
Grafton
Clarksburg
Parkersburg
Charleston
Huntington
Ashland
Portsmouth
Frankfort
Lexington
Kokomo
Muncie
Danville
Peoria
Springfield
Mattoon
Terre Haute
Vincennes
Harrisburg
Cairo
Paducah
Clarksville
Paris
Columbia
Memphis
Florence
Huntsville
Decatur
Gadsden
Harlan
Bristol
Kingsport
Johnson City
Asheville
Roanoke
Radford
Greensboro
Charlotte
Spartanburg
Greenville
Columbia
Allegheny River
Monongahela River
Muskingum River
Scioto River
Miami River
Licking River
Kentucky River
Salt River
Green River
Wabash River
Cumberland River
Tennessee River
OHIO RIVER

Introduction

Consideration of the acid mine drainage problem by the Ohio River Pollution Survey has been largely through the assembly and analysis of existing data. In this connection, the assistance of the Office of Mine Sealing, U. S. Public Health Service is deserving of special mention. Records accumulated by that office, working with the Works Progress Administration over a period of eight years, proved to be of great value.

Certain field studies were undertaken. A laboratory unit, stationed at Morgantown, West Virginia, conducted a study of Deckers Creek during the latter half of 1940 and the first half of 1941. In addition, the effect of acid mine drainage is reflected in the results from the regular comprehensive stream sampling program conducted throughout the Ohio River Basin.

A section of the Main Report of the Ohio River Pollution Survey has been devoted to the problem of acid mine drainage and that section with new table and figure numbers is included in this supplement as a summary and one of five general subdivisions into which this presentation is divided, as follows:

Summary for Main Report includes acid loads, costs and acid reduction by mine sealing, features of a mine acid control program and summarized details of such a program for the upper Ohio River Basin.

General Features including history and magnitude of the coal mining industry; types of mines, cause of acid formation, theory and practice of remedial measures and legal features including State and Federal statutes and court decisions.

Presentation of Field Data including present acid load and its distribution in as much detail as the data warrants, the status of present remedial measures, the effects of acid mine drainage and the type, extent and magnitude of damages caused.

Presentation of Laboratory Data making reference to the Morgantown, West Virginia, and regular sampling results. Mention is made of stream quality trends over a period of years as indicated by water plant records.

Discussion including presentation of a suggested comprehensive program to control acid pollution by further mine sealing and the use of flow regulation. Estimates of cost are included, together with financial justification for the program. The suggested program of acid pollution control is correlated with a parallel program of organic pollution control.

Summary for Main Report

Acid drainage from coal mines affects the streams throughout the area covered by the Ohio River Basin coal fields, (see Figure Ac-1). In Pennsylvania and West Virginia, the two largest bituminous coal producing states, the problem dominates the stream sanitation picture. The present situation exists despite the fact that in these two states only 5.1 percent of the coal deposit has been mined out or lost. The present survey has conducted a study of the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Particular attention has been directed to control measures involving mine sealing and flow regulation, particularly by multiple purpose use of flood-control and other purpose reservoirs. Studies and demonstrations by the U. S. Bureau of Mines of the possible accomplishments of mine sealing have shown that acid control at the mine is practical at reasonable cost, and a start, made in the form of a Works Progress Administration program (see Figure Ac-2) of sealing abandoned mines with U. S. Public Health Service and State cooperation, has confirmed (see Figure Ac-3) the earlier work. The present sealing program, however, is not a continuing activity having been discontinued from time to time in some states. Provision for essential maintenance is lacking. Flow regulation by flood-control reservoirs built by the U. S. Engineer Department has had a beneficial effect. Aggressive prosecution of a suggested remedial program is amply justified, particularly in the Pittsburgh District where tangible monetary benefits can be shown in excess of remedial costs. Remedial measures are imperative to insure the future of the principal streams in the mining areas

Acid Load Reduction by Sealing

Mine acid loads in the major tributaries of the Ohio River Basin as originally measured and after present sealing and suggested sealing under 1940 restrictions are given on Figure Ac-2 and Table Ac-1. Total basin acid loads from this table and the estimated load following a sealing program with 1940 restrictions modified are as follows:

Original mine acid load	2,500,000	Tons	per	year
Reduction, to date, by sealing	700,000	"	"	"
Present mine acid load	1,800,000	"	"	"
Possible further reduction by sealing under 1940 restrictions	600,000	"	"	"
Load after sealing under 1940 restrictions	1,200,000	"	"	"
Possible further reduction with 1940 restrictions modified	600,000	"	"	"
Estimated ultimate residual load	600,000	"	"	"

The sealing program under 1940 restrictions is based on a cost limitation of $10.00 per ton of acid per year and sealing only in areas not connected to active ventilation systems. Modified restrictions would permit sealing operations in worked-out sections of active mines.

The cost and benefit estimates, discussed later, apply to work necessary to complete a sealing program under 1940 restrictions and the report discusses this completion as a first objective.

Free mineral acid from waste pickle liquor is estimated at 3.4 percent (see Table Ac-8) of the present total free and combined mine acid load. Acid from hydrolized iron sulphates may be minor or as high as 10 times this quantity depending on the hydrolysis equilibrium.

Mine Sealing Costs

Mine sealing costs to date in the Ohio River Basin, as shown in Table Ac-2, have been about $5,400,000. To complete a sealing program under 1940 restrictions will cost an estimated additional $5,500,000. Annual charges of interest (3½%), amortization (0.7% based on 3½% interest and a 50 year life), inspection (2%) and maintenance (7 to 10%) are about 15 percent or $1,635,000 on the total of these two sums of $10,900,000. This is about 4 mills per net ton of production and confirms an estimate of the Office of Mine Sealing, U. S. Public Health Service. These and other estimates of future mine sealing costs are believed conservatively high as they are based primarily on past experience with Works Progress Administration programs with the dual purpose of providing relief and improving mine acid conditions.

Fig. Ac-2

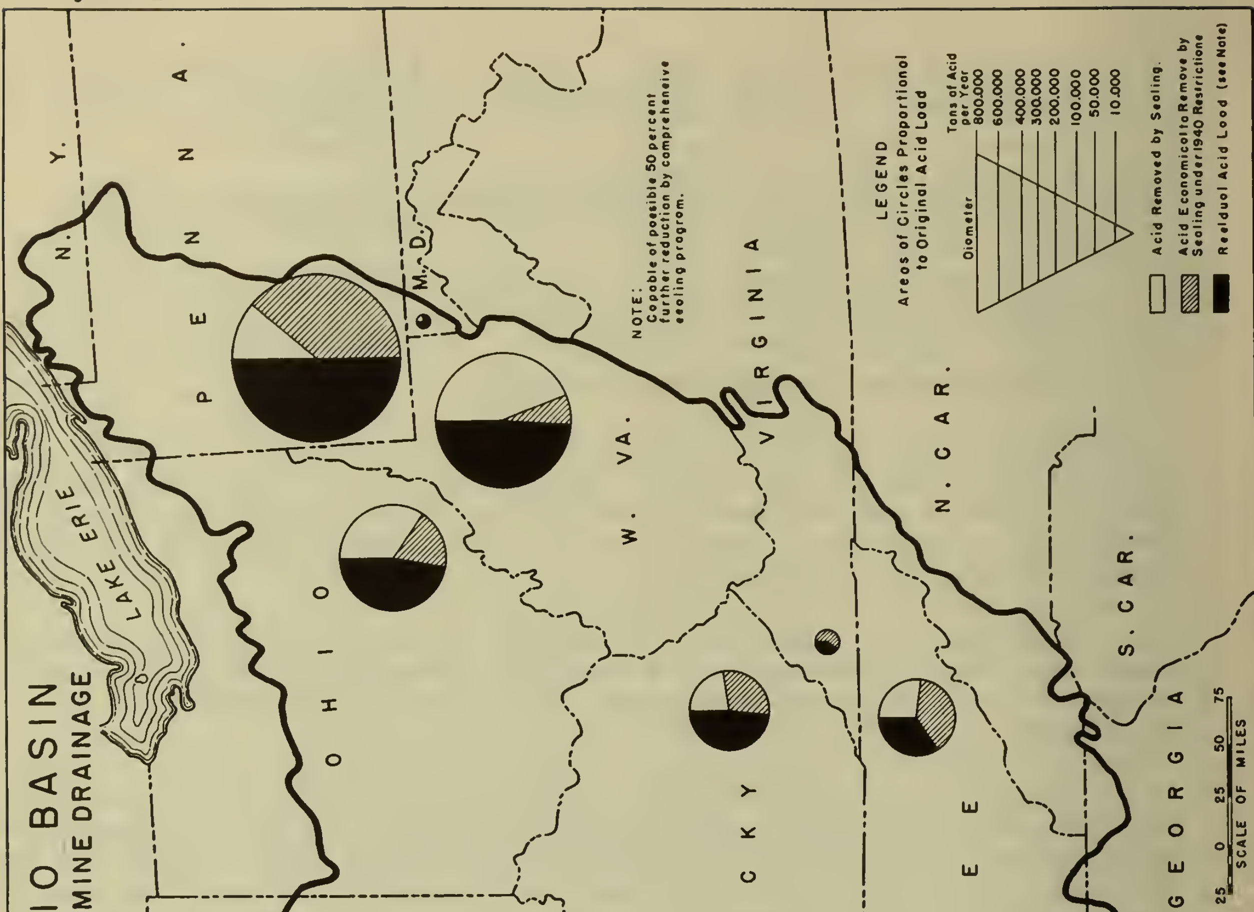

OHIO BASIN
ACID MINE DRAINAGE
LAKE ERIE
N. Y.
P E N N A.
M. D.
OHIO
W. VA.
V I R G I N I A
INDIANA
ILLINOIS
K E N T U C K Y
N. CAR.
T E N N E S S E E
S. CAR.
GEORGIA
A L A.
M I S S.
N
NOTE:
Capable of possible 50 percent further reduction by comprehensive sealing program.
LEGEND
Areas of Circles Proportional to Original Acid Load
Diameter
Tons of Acid per Year
800,000
600,000
400,000
300,000
200,000
100,000
50,000
10,000
Acid Removed by Sealing.
Acid Economical to Remove by Sealing under 1940 Restrictions
Residual Acid Load (see Note)
25 0 25 50 75
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1941

Table Ao-1 Acid Mine Drainage - Summary by Tributary Drainage Basins and States of Original Classified Mine Acid Loads, Intensity per Square Mile, Acid Removed by Sealing, Estimated Acid Economical to Remove under 1940 Restrictions and Residual Mine Acid Loads.

Tributary Drainage Basin and State	Drainage Area	Original Acid Load as $CaCO_3$: Active Mines	Original Acid Load as $CaCO_3$: Marginal (1) Mines	Original Acid Load as $CaCO_3$: Abandoned Mines	Original Acid Load as $CaCO_3$: Total Mines	Original Acid Load as $CaCO_3$: Total Mines	Sealed Mines: Original Acid Load	Sealed Mines: Efficiency	Acid Removed by Sealing	Present Acid Load	Economical to Remove in Addition By Sealing	Residual Acid Load After Sealing under 1940 Restrictions (2)	Residual Acid Load After Sealing under 1940 Restrictions (2)
	Square Miles	Tons per Year	Tons per Year	Tons per Year	Tons per Year	Tons per Sq.Mi. per Year	Tons per Year	Percent	Tons per Year	Tons per Year	Tons per Year	Tons per Year	Percent
Minor Tributary Basins - Pa.	1,290	27,380	11,320	10,697	49,397	38.3	14,100	64	9,030	40,367	15,050	25,317	51
Ohio	6,450	21,100	7,400	85,000	113,500	17.6	45,820	54	24,750	88,750	40,200	48,550	43
W.Va.	3,005	7,579	764	18,464	26,807	8.9	14,028	65	9,120	17,687	1,770	15,917	59
Ky.	5,680	4,700	1,300	11,200	17,200	3.0	7,854	50	3,927	13,273	4,900	8,373	49
Ind.	3,480	2,978	64	10,013	13,055	3.8	6,964	87	6,060	6,995	496	6,499	50
Ill.	1,645	356	1,804	411	2,571	1.6	305	70	214	2,357	1,000	1,357	53
Total	21,550	64,093	22,652	135,785	222,530	10.3	89,071	60	53,101	169,429	63,416	106,013	48
Alle. R. except Kiski.	9,838	26,457	6,760	50,244	83,461	8.5	24,040	78	18,750	64,711	32,330	32,380	39
Kiskiminetas River	1,892	223,896	23,805	73,988	321,689	170.0	20,270	54	10,954	310,735	132,630	178,105	55
Allegheny River Total	11,730	250,353	30,565	124,232	405,150	34.5	44,310	67	29,704	375,446	164,960	210,486	52
Monon. except Yough.	5,648	438,274	39,064	223,634	700,972	124.1	380,026	66	251,900	449,072	115,630	333,442	48
Youghiogheny River	1,732	141,735	25,609	52,340	219,684	126.8	29,270	78	22,742	196,942	83,050	113,892	52
Monongahela R. Total	7,380	580,009	64,673	275,974	920,656	124.7	409,296	67	274,642	646,014	198,680	447,334	49
Beaver River	3,145	5,480	988	10,920	17,388	5.5	5,376	42	2,280	15,108	6,500	8,608	50
Muskingum & Hocking R.	9,225	37,700	14,600	163,500	215,800	23.4	170,000	54	91,400	124,400	19,000	105,400	49
Little Kanawha River	2,320	323	2	493	818	0.4	716	65	470	348	50	298	36
Kanawha River	12,300	9,210	995	22,650	32,855	2.7	21,157	65	13,750	19,105	2,170	16,935	52
Guyandot River	1,670	15,680	614	3,890	20,184	12.1	14,333	65	9,320	10,864	1,330	9,543	47
Big Sandy River	4,280	16,236	8,997	35,699	60,932	14.2	26,324	56	14,738	46,194	18,320	27,874	46
Scioto River	6,510	4,900	2,400	16,800	24,100	3.7	11,540	54	6,230	17,870	7,100	10,770	45
Little Miami River	1,755	0	0	0	0	0	-	-	-	-	-	0	-
Licking River	3,670	-	-	-	Slight	-	-	-	-	-	-	0	-
Miami River	5,385	0	0	0	0	0	-	-	-	-	-	0	-
Kentucky River	6,940	10,900	3,200	27,800	41,900	6.0	22,865	50	11,433	30,467	9,520	20,947	50
Salt River	2,890	0	0	0	0	0	-	-	-	-	-	0	-
Green River	9,220	26,500	7,900	42,100	76,500	8.3	30,230	50	15,115	61,385	23,140	38,245	50
Wabash River	33,100	26,777	3,174	79,631	109,582	3.3	54,054	87	47,040	62,542	30,403	32,139	29
Saline River	1,235	-	-	-	Slight	-	-	-	-	-	-	0	-
Tradewater River	995	3,000	1,500	3,400	7,900	7.9	1,730	50	865	7,035	3,270	3,765	48
Cumberland River	18,000	53,610	13,045	198,115	264,770	14.7	105,056	65	68,862	195,908	93,070	102,838	39
Tennessee River	40,600	4,960	1,145	32,063	38,168	0.9	20,239	80	16,200	21,968	10,770	11,198	29
Unclassified - Va.	7,175	-	-	-	18,750	2.6	0	-	0	18,750	11,070	7,680	41
TOTAL	203,900	1,109,731	176,450	1,173,052	2,477,983	12.2	1,026,288	64	655,150	1,822,833	662,769	1,160,064	47
Alabama	6,810	0	0	0	0	0	-	-	-	-	-	0	-
Georgia	1,490	0	0	0	0	0	-	-	-	-	-	0	-
Illinois	11,440	356	1,804	411	2,571	0.2	305	70	214	2,357	1,000	1,357	53
Indiana	29,135	29,775	3,238	89,644	122,637	4.2	61,018	87	53,100	69,537	30,899	38,638	32
Kentucky	39,375	88,900	31,700	180,000	300,600	7.6	129,000	50	64,500	236,100	89,500	146,600	49
Maryland	430	535	79	847	1,461	3.4	570	60	342	1,119	400	719	49
Mississippi	385	0	0	0	0	0	-	-	-	-	-	0	-
New York	1,955	0	0	0	0	0	-	-	-	-	-	0	-
North Carolina	6,260	0	0	0	0	0	-	-	-	-	-	0	-
Ohio	29,570	65,000	25,000	270,000	360,000	12.2	229,600	54	123,590	236,410	68,900	167,510	46
Pennsylvania	15,620	521,513	90,003	277,833	889,349	56.9	128,237	72	91,804	797,545	349,560	447,985	50
Tennessee	33,645	25,170	5,190	160,478	190,838	5.7	74,771	80	59,800	131,038	72,440	58,598	31
Virginia (Unclassified)	7,175	-	-	-	18,750	2.6	0	-	0	18,750	11,070	7,680	41
West Virginia	20,610	378,502	19,436	193,839	591,777	28.7	402,787	65	261,800	329,977	39,000	290,977	49
TOTAL	203,900	1,109,731	176,450	1,173,052	2,477,983	12.2	1,026,288	64	655,150	1,822,833	662,769	1,160,064	47

(1) Not completely abandoned. (2) Areas connected to active ventilation systems and areas where costs exceed $10 per ton per year not included.

Fig. Ac-3

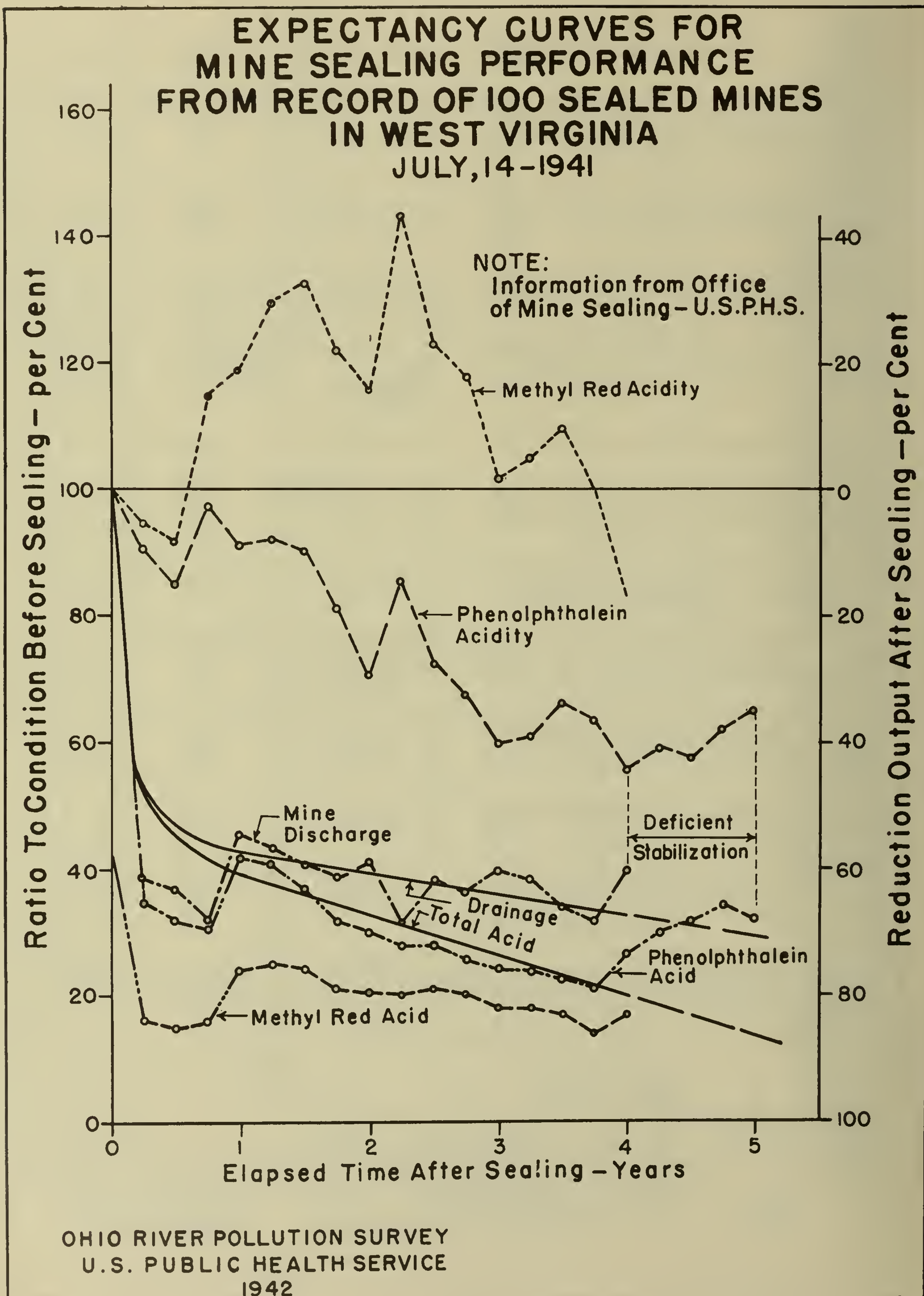

EXPECTANCY CURVES FOR
MINE SEALING PERFORMANCE
FROM RECORD OF 100 SEALED MINES
IN WEST VIRGINIA
JULY, 14-1941
NOTE:
Information from Office
of Mine Sealing - U.S.P.H.S.
Methyl Red Acidity
Phenolphthalein
Acidity
Mine
Discharge
Drainage
Total Acid
Deficient
Stabilization
Phenolphthalein
Acid
Methyl Red Acid
Ratio To Condition Before Sealing - per Cent
Reduction Output After Sealing - per Cent
Elapsed Time After Sealing - Years
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

Table Ac-2 Acid Mine Drainage - Cost of Works Progress Administration Program of Mine Sealing to Date and Estimated to Complete Restricted Mine Sealing Program, both State-wide and for the Ohio River Basin.

State	State-Wide Expenditures			Ohio Basin Expenditures	
	Total to Date (1)	Per Ton Per Yr. of Acid Sealed	Estimated to Complete Program	Estimated Total to (1) Date	Estimated to Complete Program
By States					
Illinois	$ 12,000	$ 7.26	-	(2)	-
Indiana	273,000	4.48	$ 80,000	$ 270,000	$ 80,000
Kentucky	340,000	2.66	1,200,000	340,000	1,200,000
Maryland	221,000	8.25	50,000	10,000	-
Ohio	1,935,000	8.40	400,000	1,940,000	400,000
Penn.	2,666,000	11.50	4,000,000	1,490,000	3,100,000
Tennessee	109,000	2.46	420,000	110,000	420,000
Virginia	0	-	150,000	0	150,000
W.Virginia	1,462,000	3.00	200,000	1,210,000	160,000
Total	7,018,000	5.80	6,500,000	5,370,000	5,510,000
By Basins					
Minor Tributary Basins				$ 650,000	$ 480,000
Allegheny				510,000	1,460,000
Monongahela				1,820,000	1,600,000
Beaver				60,000	50,000
Muskingum and Hocking				1,450,000	110,000
Kanawha				70,000	120,000
Guyandot				40,000	10,000
Big Sandy				70,000	240,000
Scioto				100,000	40,000
Kentucky				60,000	130,000
Green				80,000	310,000
Wabash				240,000	80,000
Cumberland				200,000	780,000
Tennessee				20,000	100,000
Total				5,370,000	5,510,000

(1) Rounded. (2) Less than 5,000.

Mine Acid Control Program

Present information indicates that correction, in large measure, of the mine acid pollution problem is practical by a comprehensive control program involving the following measures:

(a) Provision for the inspection and maintenance of present air seals and a similar provision in connection with all future mine sealing programs.

(b) Completion of the present limited (1940 restrictions) mine sealing program.

(c) Provision of reservoir capacity, presumably in primarily flood-control reservoirs, for flow regulation for acid and organic pollution control.

(d) Inauguration of an aggressive program of mine sealing with present restrictions modified.

(e) Adaptation of the better mining methods to acid control.

(f) Extension of the established practice of refraining from discharging acid waters to streams previously uncontaminated.

(g) Clarification of the laws governing mine drainage to facilitate the corrective program.

Upper Ohio Basin

For illustrative purposes and to indicate cost to benefit relationships, special studies have been made in the upper Ohio River Basin area or the area above the Ohio-West Virginia-Pennsylvania State line. Estimates have been made of accomplishments, costs and benefits resulting from application of the first three of these items, namely, mine sealing, maintenance and flow regulation. Any study of reservoir development should include consideration of organic pollution control and the program studied considers both organic and acid pollution.

Damages - Damages capable of monetary evaluation caused by acid mine drainage include neutralization and softening costs to domestic and industrial water supplies and corrosion of steamboats, barges, power plant condensers and river and harbor structures. These damages in the area above the Ohio-West

Virginia-Pennsylvania State line, totaling about $2,000,000 per year, are shown on Table Ac-3. Equally important, but intangible or unevaluated, damages are to water supply due to manganese, to recreation through the destruction of normal aquatic life, to agricultural uses, to highway structures, to the mines themselves, and indeterminate but serious damages to the public health due to rapid fluctuations in quality as reported by water plant operators. Mine acid is a deterrent to organic pollution abatement, as incentive for abatement measures is lacking if the result is a stream suitable only for disposal of mine waters. Mine acid is not a safeguard to public water supplies as the rapid increase in flow during a freshet may bring sufficient alkalinity to neutralize the acidity and eliminate any germicidal effect there may be.

Table Ac-3 Acid Mine Drainage - Summary, as of 1940, of Annual Damages, Capable of Accurate Estimation and Caused by Acid Mine Drainage above the Ohio-West Virginia-Pennsylvania State Line.

		Total Annual Damages
Domestic Water Supplies.		$ 364,000
Industrial Water Supplies.		407,000
Steamboats and Barges.		1,143,000
Power Plants		76,000
River and Harbor Structures.		76,000
Floating Plant (U.S.E.D.).		5,000
Total - 1940		2,071,000
Future Estimate - 1950	Based on estimated future quality but	2,630,000
Future Estimate - 1960	no increase in use	$3,190,000

Mine Sealing - Data on mine acid loads before and after various stages of sealing, similar to that given on Table Ac-1 for the upper Ohio River Basin are as follows:

Original mine acid load	1,375,000	Tons per year
Reduction, to date, by sealing	313,000	" " "
Present mine acid load	1,062,000	" " "
Possible further reduction by sealing under 1940 restrictions	379,000	" " "
Load after sealing under 1940 restrictions	683,000	" " "

The completion of a mine sealing program in this area under 1940 restrictions will cost an estimated $3,250,000. Annual charges, including interest, amortization, inspection and maintenance as already enumerated, are 15 percent or $488,000 on this expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000 per year, making a total of $870,000 per year. As shown on Figure Ac-3 if these existing seals are not maintained, the benefits already realized may easily be lost making it necessary to repeat the expenditure.

Flow Regulation - The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity but there will still remain acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage. The estimated reservoirs selected for acid control are the largest that can be used without storing for periods greater than one year. Utilization of increased capacity beyond this point would be infrequent and the unit value would therefore be reduced. Reservoir capacities selected in the upper Ohio River Basin area under these condition are as follows:

Allegheny Basin	210,000 Acre-feet
Monongahela Basin	370,000 " "
Total	580,000 " "

Organic pollution in the upper main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 c.f.s. during the warm summer months (25°C. or 77°F. average monthly air temperature) and progressively lesser flows as temperatures decrease. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drouth occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drouth. A valuable partial organic pollution control would be available during a year such as 1930.

Storage required for organic pollution abatement is 430,000 acre-feet (except in 1930) while total storage selected for acid control is 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Benefits and Costs - Benefits of the combined program due to acid control are due to a reduction in the damages detailed on Table Ac-3. Benefits to organic pollution control are due to a reduction in the cost of needed sewage and industrial waste treatment.

Reduction in maximum monthly acidities equitably assigned to the two items; mine sealing and flow regulation, of this program are as follows:

	Acidity (1) - P.P.M.	
	Allegheny at Aspinwall	Monongahela abv.McKeesport
Present monthly maximum	23	33
Reduction by sealing (2)	22	19
Reduction by reservoirs (2)	14	10
Resulting monthly maximum	(3)	4

(1) To Methyl Red on Allegheny and Methyl Orange on Monongahela.
(2) Equitably assigned or average improvement if remedy applied constructed first or second. As a rule, projects applied first show increased benefits at expense of later projects.
(3) 13 p.p.m. minimum alkalinity.

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela and upper Ohio River Basin due to the suggested mine sealing and flow regulation programs total $1,133,000 per year. This estimate is believed conservative as it is based on 1940 damages instead of greater possible future damages and it does not include benefits to unevaluated and intangible items. Deducting the cost of sealing of $870,000 per year from these benefits leaves $263,000 per year that can be spent on reservoir construction for acid and hardness reduction.

In correcting sewage and organic industrial waste pollution without flow regulation, a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is $300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional $300,000.

While the flow regulation is designed primarily for acid pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a valuable aid in organic pollution control. The two flow regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic pollution control. An examination of flow and acidity records indicates that acid control and organic pollution abatement can both be accomplished with the exception of one month (also excepting 1930) in ten years and this accomplishment has been taken as satisfactory.

Annual benefits to flow regulation include $263,000 left after deducting mine sealing costs from acid and hardness control benefits, plus $300,000 for organic pollution control at Pittsburgh and $300,000 for organic pollution control benefits at Cincinnati, making a total of $863,000 per year. For a storage of 580,000 acre-feet, the annual benefits or the amount that can be economically spent per acre-foot per year is $1.49.

A summary of the cost and benefit relation is as follows:

	Annual Benefits and Costs
Benefits - Acid Control	$1,133,000
Cost - Mine Sealing To date and Future	870,000
Balance - Acid Control for Reservoirs	263,000
Benefits - Organic Pollution Control	
Pittsburgh	300,000
Cincinnati	300,000
Total available for reservoirs	$863,000
Per Acre-Foot	$1.49

Reservoir benefits are, in large measure, due to equalizing and surge reducing effects following mine sealing in order to develop full benefits from the sealing program. The balance for reservoirs indicated is, therefore, available to the extent shown only if and when the mine sealing program is assured. Mine sealing, on the other hand, can be justified beyond reasonable doubt as a single independent remedial measure.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-Upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

General Features

History of Industry

The history of the acid mine drainage problem parallels the history of the industry and there are certain general features of the industry which have a marked influence and must be considered in any study of the acid problem.

Coal mining in the United States and in the Ohio Basin has reached its present magnitude within the last 25 years and the acid mine drainage problem has become increasingly acute during that time. The industry is large in itself and is vital to all industrial activity in its area. The coal mining industry, through its drainage, damages a prosperous area at the same time that it is largely responsible for the very existence of the prosperity of that area. Location and area of the Ohio Basin coal fields are shown on Figure Ac-1.

Early Development - The first recorded production of coal was in 1750 when 500 tons were mined in Virginia. There was no other important production until 1759 when a coal mine was opened on the Monongahela River opposite Fort Pitt, now Pittsburgh. In 1793 the United States produced about 63,000 tons of coal which was mined mainly in Pennsylvania and West Virginia In 1840 when the first Federal census was taken coal production was approximately 2,000,000 tons. From 1841 to 1869 annual production grew to about 15,000,000 tons. From 1841 to 1869, except for 1865, Pennsylvania anthracite production exceeded total bituminous production. Since then bituminous production has been greater. Until 1873 imports exceeded exports but since there has been a considerable export balance.

Recent Trends - In the period, roughly 1890 to 1920, coal mining was one of the nation's most rapidly growing industries. Production approximately doubled every 8 to 10 years but following the first world war peak, reached in 1918, the general long-time trend has been downward. Reasons for this downward trend are believed to be: (1) slower growth of population and industry, (2) fuel economy resulting from better burning equipment and careful combustion control, (3) competing fuels mainly oil and gas. In 1900 coal contributed 89% of the energy derived from the mineral fuels (coal, oil and gas) and water power. By 1937 this had dropped to 54%. Natural gas and petroleum contributed 43% and water power 3%. In general, the coal industry has been losing ground in most of the postwar period.

Present Magnitude

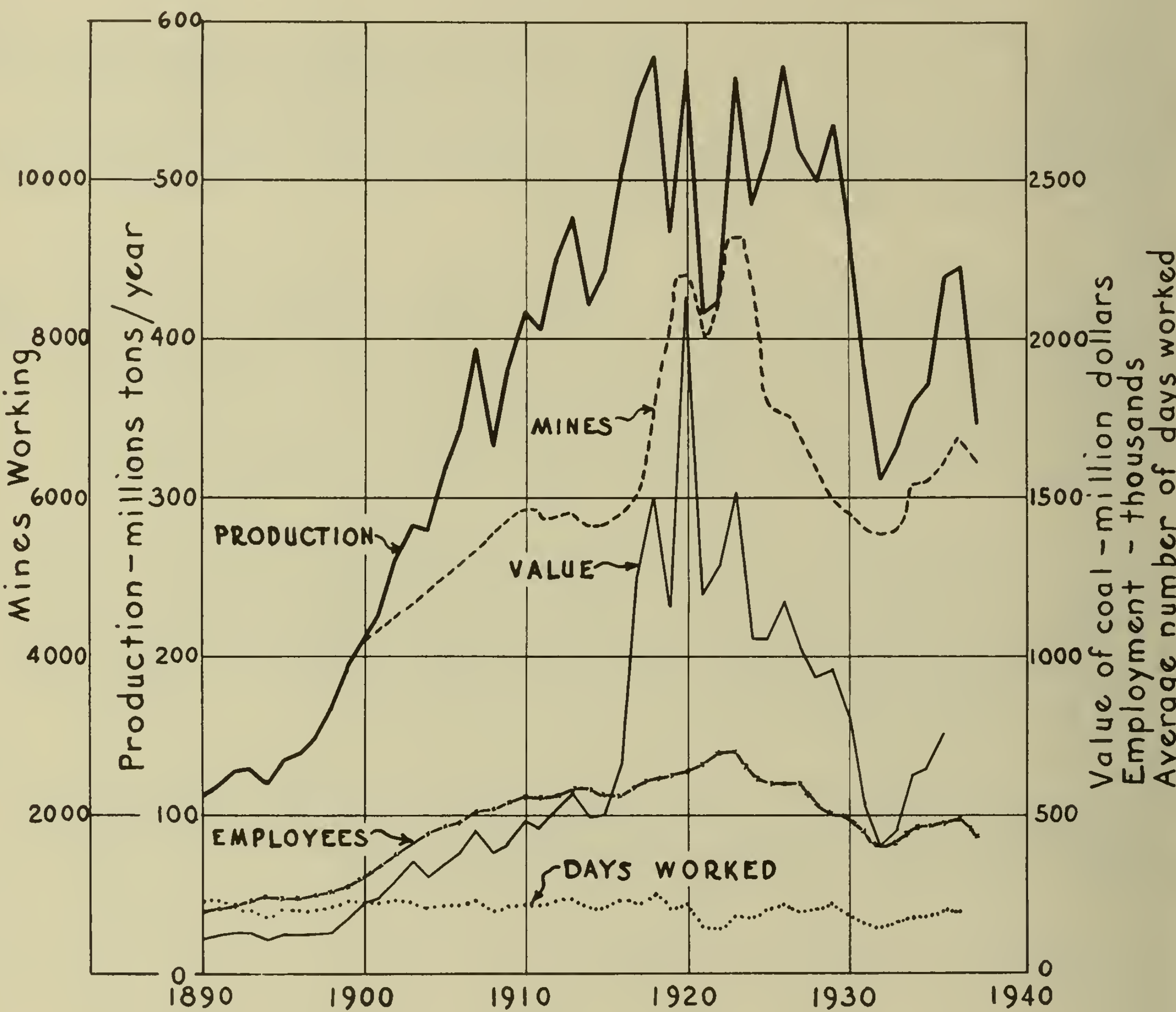
The annual value of coal production in five states exceeds the value of the entire annual national output of gold, silver, copper, lead, zinc and aluminum. In West Virginia the number of men employed by coal mines exceeds the total supported by manufacturing industries and in Kentucky the number is not much less. In Pennsylvania the bituminous coal mines normally employ more men than the steel industry.

The coal industry is a large power consumer and spends large sums annually for machinery, tools, timber, etc. In 1935 the industry's power bill was about $25,000,000.00 and approximately $75,000,000.00 were spent for supplies and equipment. Investment in the industry is estimated to be of the order of three billion dollars with the bituminous coal mining investment at from 2 to 2.5 billion dollars. In Pennsylvania in 1929 the investment was approximately 500 million dollars.

In 1923 the average number of men employed at operating mines including the anthracite districts was 862,536, in 1929, 654,444, in 1937, 585,500. The value at the mines of the coal produced was $1,338,000,000 in 1929 and $960,000,000 in 1937. In prosperous years coal has constituted as much as 35% of the total railroad freight tonnage, corresponding to 23% of the railroad freight revenue.

Table Ac-4 and Figure Ac-4 present information on the growth since 1890 and the present magnitude of the coal industry in terms of annual net tons production, value of product, employees, days worked and number of mines in operation.

Table Ac-5 shows total coal resources and the maximum coal production by Ohio Basin states.



BITUMINOUS COAL INDUSTRY IN U.S.

Data: Minerals Yearbook
U.S. Bureau of Mines

Table Ac-4 Acid Mine Drainage - Statistics of U. S. Bituminous Coal Industry.
(From Minerals Year Book - 1938)

	Production Millions of Net Tons	Value Millions of Dollars	Men Employed (1000's)	Ave.No. Days Worked	Days lost on acct. strikes	Value per Ton (Dollars)	Net Tons per man day	% Cut by Machine	Mined by Stripping Mil. Net Tons
1890	111	110	192	226		0.99	2.56	-	
91	118	117	206	223		.99	2.57	5.3	
92	127	125	213	219		.99	2.72	-	
93	128	123	230	204		.96	2.73	-	
94	119	108	245	171		.91	2.84	-	
95	135	116	240	194		.86	2.90	-	
96	138	115	244	192		.83	2.94	11.9	
97	148	120	248	196		.81	3.04	15.3	
98	167	133	256	211		.80	3.09	19.5	
99	193	168	271	234	8	.87	3.05	22.7	
1900	212	221	304	234	5	1.04	2.92	24.9	
01	226	236	340	225	2	1.05	2.94	25.6	
02	260	291	370	230	7	1.12	3.06	26.8	
03	283	352	416	225	3	1.24	3.02	27.6	
04	279	306	438	202	8	1.10	3.15	28.2	
05	315	335	461	211	2	1.06	3.24	32.8	
06	343	381	478	213	28	1.11	3.36	34.7	
07	395	451	513	234	1	1.14	3.29	35.1	
08	333	374	516	193	11	1.12	3.34	37.0	
09	380	405	543	209	1	1.07	-	37.5	
1910	417	469	556	217	35	1.12	3.46	41.7	
11	406	451	550	211	2	1.11	3.50	43.9	
12	450	518	549	223	10	1.15	3.68	46.8	
13	478	565	572	232	5	1.18	3.61	50.7	
14	423	493	584	195	19	1.17	3.71	51.7	1.3
15	443	502	557	203	4	1.13	3.91	55.0	2.8
16	503	665	561	230	4	1.32	3.90	56.5	3.9
17	552	1249	603	243	4	2.26	3.77	55.5	5.8
18	579	1492	615	249	1	2.58	3.78	55.9	8.3
19	466	1161	622	195	25	2.49	3.84	59.2	5.6
1920	569	2130	640	220	6	3.75	4.00	59.8	8.9
21	416	1200	664	149	3	2.89	4.20	65.6	4.7
22	422	1275	688	142	78	3.02	4.28	63.2	9.9
23	565	1515	705	179	2	2.68	4.47	66.9	11.8
24	484	1063	620	171	7	2.20	4.56	69.5	13.6
25	520	1060	588	195	2	2.04	4.52	70.6	16.9
26	573	1183	594	215	1	2.06	4.50	71.7	16.9
27	518	1030	594	191	45	1.99	4.55	72.2	18.4
28	501	934	522	203	8	1.86	4.73	73.8	19.8
29	535	953	503	219		1.78	4.85	75.4	20.3
1930	468	795	493	187		1.70	5.06	77.5	20.2
31	382	589	450	160	3	1.54	5.30	79.1	18.9
32	310	407	406	146		1.31	5.22	78.8	19.6
33	334	446	419	167	9	1.34	4.78	80.0	18.3
34	359	628	458	178		1.75	4.40	79.2	20.8
35	372	658	462	179		1.77	4.50		23.6
36	439	768	477	199		1.76	4.62		28.1
37	446		492	193		2.10	4.69		31.8
38	345		435			2.04			

Table Ac-5 Acid Mine Drainage - Bituminous Coal Resources as of End 1936(1) and Maximum Annual Production and Total Production by States.

State (2)	Bituminous Coal Resources					Bituminous Coal Production			
	Original Deposits	Production	Losses (3)	Reserves (4)	Mined Out and Lost	Year of Maximum Production	Maximum Annual Production	Total Production from earliest record to end 1937	Per cent of Total U.S. Production
	Millions of Net Tons (2,000 lbs.)				Per Cent		Net Tons (2,000 lbs.)		
Georgia	933	11	6	916	1.8	1903	416,000	-	-
Illinois	201,400	2,354	1,251	197,795	1.8	1918	89,291,000	2,405,891,000	12.95
Indiana	53,051	703	374	51,974	2.0	1918	30,679,000	721,091,000	3.88
Kentucky	123,327	1,163	618	121,546	1.4	1927	69,124,000	1,209,969,000	6.51
Maryland	8,043	238	127	7,678	4.5	1907	5,533,000	239,947,000	1.29
N.Carolina	68	1	1	66	2.9	1922	79,000	-	-
Ohio	93,967	1,310	696	91,961	2.1	1920	45,878,000	1,335,547,000	7.19
Penna.	112,148	5,777	3,070	103,301	7.9	1918	178,551,000	5,888,186,000	31.70
Tenn.	25,665	245	130	25,290	1.5	1910	7,121,000	250,197,000	1.35
Virginia	21,149	328	174	20,647	2.4	1926	14,133,000	349,074,000	1.88
W.Virginia	152,544	3,132	1,664	147,748	3.1	1927	145,122,000	3,250,331,000	17.50
Total	792,295	15,262	8,111	768,922	3.0	-	-	15,650,233,000 (5)	84.25

(1) From National Resources Committee Report. Energy Resources and National Policy, p.283.
(2) Includes entire State, parts of which are outside of the Ohio River Basin.
(3) Estimated average loss 34.7%
" avoidable " 19.4%
" minimum " 15.3%
(4) Therefore future recovery, 65.3 to 84.7 percent.
(5) Total bituminous coal production in U.S. from earliest record to end 1937 = 18,573,689,000 tons.

Economic Problems

The problems of the bituminous coal industry are associated with the abundance of the coal resources. This condition led to the opening of great numbers of mines and the development of excess capacity. The surplus capacity and the division of the industry into many small and large units scattered over 32 states early led to severe competition. The war (1914-1918) led to further expansion. Fuel shortages during and following the war were due to congestion and railway transport and strikes rather than lack of producing power. After 1923 the problems of surplus capacity, declining prices and competition began to be felt in intensified form and the coal industry entered a period of serious depression. From 1924 to 1929, when business in general was highly prosperous, bituminous coal mining suffered depression. The average sales realization f.o.b. mines decreased from $2.68 per ton in 1923 to $1.78 in 1929. More than 200 million tons of annual mine capacity was forced out of production and over 3,000 commercial mines were shut down or abandoned. Approximately 200,000 mine workers lost employment as a result.

The mortality rate among coal mines is notoriously high. Unfortunately, data collected do not reflect adequately this mortality because they pertain principally to the larger and more stable mining companies. It is known, however, that each year a large number of mines are abandoned, either temporarily or permanently. The U. S. Coal Commission in 1923 made a study of the probable life of certain mines. It was found that the average life expectancy of bituminous coal mines, excluding abandonment, ranged from about 12 years in some of the western mines to about 46 years in the Alabama mines. Bituminous coal mines of West Virginia reported a life expectancy of 42 years; those in Maryland, Kentucky, Virginia and Tennessee 43 years; Illinois and Indiana 32; Pennsylvania 29; and Ohio 24 years. The average age of mines studied ranged from 11 years in the western fields to about 20 years in the older eastern fields.

Following emergency regulation by the government (Food & Fuel Control Act 1917) there has been a trend toward the conviction that the coal industry's problems are not those of a temporary recession but rather problems requiring basic adjustments. The chief lines of attack have been as follows:

(1) Self-regulation by the industry.

(2) Dual regulation by the industry in cooperation with the Federal Government.

(3) Regulation under acts passed by Congress as the Conservation Act (Guffey-Snyder Coal Act) of 1935 and the Bituminous Coal Act of 1937 (Guffey-Vinson Coal Act). (The latter is now in force).

The outlook is for additional regulation in some form.

Types of Mines

Coal mines may be classified into four types based on the method of gaining access to the coal beds:

(1) Strip Mining - A limited proportion of the coal is so near the surface that the overburden of rock and dirt may be removed with power shovels leaving the coal exposed for loading into cars. Strip mining usually costs less than underground methods.

(2) Drift Mining - A tunnel is driven into the side of a hill at the coal outcrop and the coal is mined out by following the contour of the bed. This eliminates the need for driving tunnels into rocks in order to reach the coal.

(3) Slope Mines - In this type of mine tunnels on grades low enough to permit mine cars to be pulled over tracks are driven into the coal beds along which active mining is to proceed. More than half of all coal mined is taken from drift or slope mines.

(4) Shaft Mines - A vertical opening (or shaft) is driven to the coal to be mined out and mining proceeds along the coal vein from the bottom of the shaft. The average depth of shaft mines in 1926 was 262 feet. Increase in depth magnifies problems of entry, exit, ventilation, support of cover and drainage. Abandoned shaft mines are less of an acid problem than other types as, in many cases, acid discharge stops as the mine becomes flooded when mining is discontinued.

Table Ac-6 Acid Mine Drainage - Approximate Percent Distribution of Mines by Type of Opening

State	Percent			
	Shaft	Slope	Draft	Strip
Alabama	8	60	28	4
Illinois	35	38	17	10
Indiana	85	2	0	13
Kentucky	9	10	81	0
Ohio	19	20	55	6
Pennsylvania	11	13	75	1
Tennessee	10	0	90	0
West Virginia	8	8	82	2

Cause of Acid Formation

This discussion of the cause of acid formation in mines is introduced with the observation that much is yet to be learned on this subject. There are numerous instances of record where comparable mines in the same coal bed have greatly varying acid discharges and no explanation is readily apparent. In fact, serious polluting discharges are confined to less than one-half of the mines. A proper conclusion is that research is needed and this discussion points to a possible line of attack.

Hypothesis - According to a commonly advanced hypothesis, the iron, aluminum and other sulphates and sulphuric acid often found in the drainage from coal mines are formed from the pyrite, marcasite and other minerals and ores commonly found with coal deposits by the action of water and oxygen on these materials. A typical chemical reaction, using pyrite as an example of the source of sulphur, generally considered to occur, is as follows:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

Further action may then take place, in the presence of oxygen, between ferrous sulphate and sulphuric acid as follows:

$$4FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

Then: $$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3H_2SO_4$$

Rate of Acid Formation - There is very little information available regarding the effect of oxygen reduction in mine atmosphere on the rate of acid formation. However, this effect can be considered from a hypothetical standpoint, and certain tentative conclusions drawn.

In discussing the mechanism of the reaction involved in the natural oxidation of pyritic sulphur, Burke and Downs (Technical Publication No. 769, Trans. American Institute of Mining and Metallurgical Engineers) propose the hypothesis that the observed phenomena of oxidation are probably the result of two consecutive reactions as follows:

$$FeS_2 + 3O_2 \longrightarrow FeSO_4 + SO_2 \quad (1)$$

$$2SO_2 + O_2 + 2H_2O \longrightarrow 2H_2SO_4 \quad (2)$$

The sum of these two reactions, properly balanced, is the conventional reaction:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4 \qquad (3)$$

It was further assumed by Burke and Downes that the rate of reaction (1) was extremely slow as compared to the rate of (2) and that as a consequence reaction (1) determined the rate of oxidation of the pyritic sulphur.

These assumptions were all tested experimentally and the experimental evidence confirmed the theory proposed.

Since all evidence points to the equation:

$$FeS_2 + 3O_2 \longrightarrow FeSO_4 + SO_2$$

as the controlling reaction, it should be possible to generalize the rate of this reaction, and hence the rate of acid production in terms of the concentrations of the reacting substances, FeS_2 and O_2.

According to the law of mass action, the velocity of a reaction is proportional at any moment to the molecular concentrations of the reacting components and to a constant (K) which is characteristic of the chemical nature of the reacting substances and to the temperature. At any given temperature, therefore, we may write for the oxidation of pyritic sulphur:

$$V = K\,(FeS_2)\,(O_2)^3 \qquad (4)$$

V = reaction velocity

FeS_2 = pyrite concentration

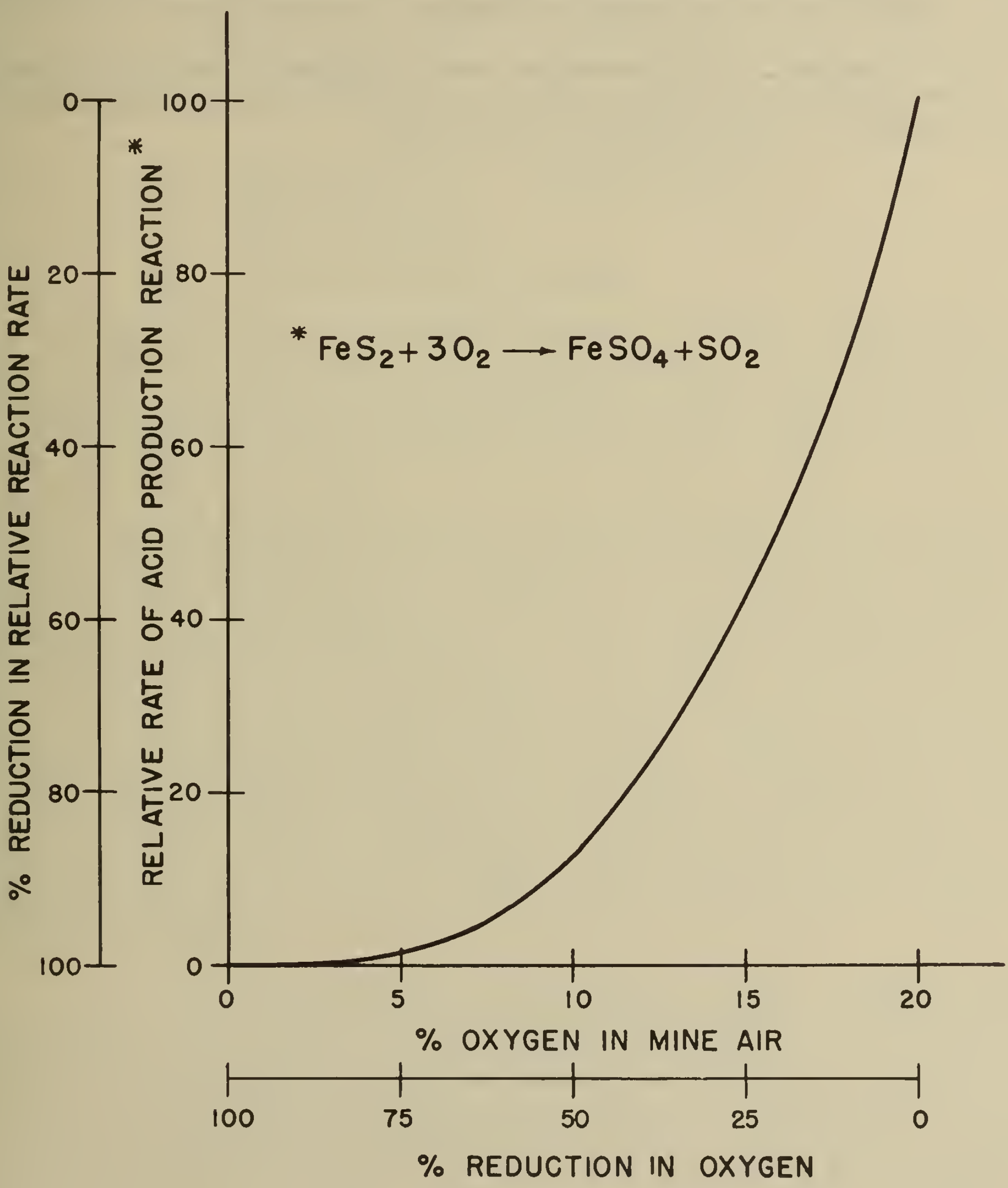
O_2 = oxygen concentration

Since the amount of pyrite and other sources of sulphur available for reaction is large, its concentration may be considered to remain unchanged. Hence we may write -

$$V = K\,(O_2)^3 \qquad (5)$$

If the basic assumptions are correct, the above equation (5) indicates that the rate of reaction (1) which governs the rate of acid formation is proportional to the cube of the oxygen concentration. From analytical examination of the equation or reference to the graphical representation, it is evident that a small reduction in oxygen produces a proportionally far greater

THEORETICAL RELATIONSHIP BETWEEN OXYGEN CONCENTRATION IN MINE AIR AND RATE OF ACID FORMATION REACTION



RELATIVE RATE ACID PRODUCTION

$$\text{Reaction} = \frac{100\,(O_2\,\text{Conc})^3}{8000}$$

reduction in reaction rate and that a reduction of 50%, corresponding to about 10% oxygen left in the mine air, produces a reduction of roughly 87% in the reaction rate.

Figure Ac-5 presents a curve showing this hypothetical rate of acid formation with reduction in atmospheric oxygen.

Although this question was studied briefly by the Morgantown laboratory unit, there are no final experimental data to support the hypothesis advanced.

Remedial Measures

Acid mine drainage has been an acute problem for several decades and its history involves extensive study of remedial methods and court action. Early efforts considered neutralization and recovery of by-products while more recent efforts have been toward prevention of formation of the acid and equalization of stream flow. Corrective efforts can be divided into five classes:

1. Mine Sealing - Abandoned Mines
2. Mine Sealing - Active Mines
3. Flow Control
4. Neutralization
5. Miscellaneous Methods.

Mine Sealing - Abandoned Mines - A most promising line of attack of the acid mine drainage problem is that of preventing acid formation by sealing abandoned mines, thus eliminating most of the oxygen which is essential for acid formation and, in some measure, reducing water entering the mine.

In 1925 the U. S. Bureau of Mines began a series of field and laboratory studies on the subject of acid mine drainage and were later able to demonstrate the feasibility of preventing acid formation by sealing. All subsequent work has been based on the foundation of these early studies and demonstration. Large scale sealing of abandoned coal mines in the last seven years has confirmed the earlier work. The reduction of acid formation is based upon the principle that the exclusion of air (oxygen) from the mines will prevent the oxidation of pyrite, marcasite, and other sources of sulphur in the presence of water. Diversion of surface water from entry into mines through cracks and caves is also done in order to minimize the amount of water in the mine and prepare these entries for surface sealing. Water in the mine is allowed to drain through trapped openings.

Air sealing, to be effective, must include a maximum of surface sealing. Thereafter, with proper maintenance, a reasonable expectation is an average reduction of about 65 percent in flow, 40 percent in phenolphthalein acidity, 10 percent in methyl red acidity and possibly 80 percent in the total quantity of acid discharged as measured in tons. There may be little immediate improvement in quality and the free acid concentration may be increased above normal for several years. Figure Ac-3 shows expectancy curves for mine sealing performance from the record of 100 sealed mines in West Virginia.

Sealing of abandoned coal mines was begun on a large scale in 1933. The program was instituted and presented through the combined efforts of the Ohio River Board of Engineers, the U. S. Public Health Service, various State Health Departments and Federal relief agencies. Work was carried on intermittently until 1935 when the program was placed on a regional basis under the Works Progress Administration and the U. S. Public Health Service with the State Health Departments cooperating.

The program has been carried on until the present time (1940) in West Virginia, Maryland, Ohio, Alabama, Tennessee and Indiana. Although far from completed, work was stopped in Pennsylvania and Kentucky in 1938. Work in Illinois has been largely completed. No work has been done in Virginia.

The mine sealing program in the past has been a relief measure and, as a result, activities have tended to concentrate in areas of greatest relief need rather than in areas of greatest acid control need. Considered primarily as a relief measure, this tendency has been proper. In general, a cost limitation of $10.00 per ton per year has been in effect. Such economical projects should be attacked first. Indications are that extension of this cost limitation to a somewhat higher figure is justified particularly in critical areas. The present mine sealing authorization is for abandoned mines and does not cover areas that are connected with an active ventilation system. In a truly comprehensive program such areas should, in many cases, be brought within the range of control.

Any stream improvement program, be it an organic pollution remedial measure or one for acid control, requires a continuing effort in the form of sewage or industrial waste treatment plant operation or mine seal inspection and maintenance. This feature is of particular importance in connection with mine sealing. In some states, provisions for maintenance are inadequate and the seals are reported to be breaking down. A mine sealing program should include provision for inspection and maintenance or the program will be of only passing benefit.

Inspection is estimated at 2 percent. Maintenance may be 15 percent or higher for a few years reducing to a low figure as the seal becomes stabilized. A range of from 7 to 10 percent will probably represent average conditions. If interest ($3\frac{1}{2}$%) and amortization (0.7 percent based on a 50 year life and $3\frac{1}{2}$ percent interest) are added, annual charges will total about 15 percent.

Mine Sealing - Active Mines - In carrying out possible air sealing activities in connection with active mines, it is necessary to enter the mine where active mining operations are still in progress. This is properly the jurisdiction of the mining departments and any proposed activity is a matter for State mining department supervision. However, acid from operating mines presents a pollution problem and is therefore also within the jurisdiction of pollution control agencies. This problem, therefore, requires close coordination of the activities of the two administrative agencies.

The acid produced in active mines represents a large proportion of the total mine acid production and to date no extensive attempts have been made to offset this load. However, based upon the demonstrated success of sealing abandoned mines, the possibility of minimizing to a great extent the acid production in active mines by surface sealing for diversion of surface water and air sealing of worked-out sections in the mine is worthy of careful consideration.

With orderly panel developments of mines and the use of barrier pillars to minimize the number of openings to various portions of the mine, air sealing of worked-out sections can be accomplished at low expense. Both surface and air sealing would reduce acid production and the results of such sealing would be of great benefit not only in reducing stream pollution but also in lowering mine operating costs. Direct benefits to mine operators that would accrue through sealing may be summarized as follows:

(1) Decreased pumpage - This would result mainly from surface sealing of cracks and caves and consequent diversion of surface water from the mine. Pumping costs are a substantial operating expense item at most large mines and any reduction in water entering the mine would result in a significant saving.

(2) Lower costs for ventilation - An unsealed worked-out section requires ventilation to eliminate the hazards of gas (methane) which is encountered in many mines. This results in considerable ventilation expense chargeable to areas no longer yielding any return. If these sections were air sealed by the conventional method involving the use of a water trap, ventilation would no longer be required. Where excessive amountsof gas are encountered it would be necessary as a safety measure to provide for pressure relief by suitable means.

There may also be a benefit due to a lesser acid quality of the water but, as pointed out, this is not certain at least for a period of several years.

The net reduction in quantity of water, ventilation area and possibly quality of water on a conservative basis is ample to make sealing of worked-out sections of active mines attractive. Although detailed studies are not available, it is quite possible that savings would be sufficient to amortize the required investment. Experience with abandoned mines clearly indicates that improvement is possible in the discharge from worked-out sections of active mines. A suitable actual demonstration is needed to facilitate adoption of the proposal in general practice.

The sealing of worked out sections is permissible under the mining laws of several states provided that such seals do not cause impoundment of large quantities of water under any considerable head. Such a condition would obviously be hazardous to nearby active workings. Fortunately, sealing causes no dangerous impoundment since the water can pass readily through the air seal. Sealing of worked-out areas has been practiced to a limited extent but with considerable success in one state.

Mine Sealing - Economic Considerations - The cost of sealing a mine is roughly proportional to the number of acres of the coal measures which have been mined out. However, certain mines, for reasons not thoroughly understood, produce far more acid per acre mined out than others even though all may be relatively close to each other and may have worked the same coal seams. Thus the cost of sealing a low acid producing mine may well be as high or higher than the cost of sealing a comparable mine producing much more acid. This suggests that a maximum sealing cost, based on the cost per unit weight of acid sealed, be established. Under the present program this has been set at approximately ten dollars per ton, per year. As might be expected, statewide averages for sealing work to date, as shown in Table Ac-2, have been less than this figure. However, use of such a limiting figure is restricted to large areas; and when the problem of economical use of mine sealing funds is viewed on the basis of small areal units, such as counties or small watersheds, the difficulty of applying any rigid economic standard becomes apparent. In such cases the answer to the question of how much should be spent per ton of acid sealed should be based on an estimate of how much acid removal is worth from the standpoint of various water uses. For example, on a small stream receiving the

drainage from only a few abandoned mines and no other pollution the value of acid removal or reduction might well be many times as great as the corresponding value on a similar stream subject to heavy pollution from many different sources. In the latter case the economic limit might well be far less than any state-wide or regional average standard while in the former it conceivably could be much greater.

Flow Control - In many streams, the natural alkalinity of the water is ample during normal times to neutralize the acid mine drainage load placed upon it and leave a satisfactory residual alkalinity. However, at certain times, the flow of the stream may not be sufficient to absorb the load and normal aquatic life requiring a continuous satisfactory habitat may be damaged or destroyed. It follows that if alkaline water from storage can be added at such times the damage caused by the acid mine drainage load will be greatly reduced.*

The construction of a reservoir for the sole purpose of supplying flows to neutralize acid mine drainage would be unduly expensive. However, there has been a trend in the past decade toward the construction of multipurpose reservoirs or, more commonly, toward the multipurpose use of what are primarily flood control reservoirs. Effectiveness for the specific purpose of acid control is somewhat reduced under these conditions but the neutralization of acid mine drainage need justify only a part rather than the whole cost of a reservoir. Flow control as a means of correcting acid mine drainage conditions, particularly in leveling off fluctuations, appears worthy of serious consideration.

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* In waters containing mine drainage, there are theoretical considerations that indicate that it is not strictly correct to deduct alkalinity values from acidity values. The low alkalinity values obtained in acid mine river samples may be the result, in many cases, of partial and incomplete hydrolysis of the iron salts contained therein. When such samples are added to samples which are already acid a dilution of the unhydrolyzed iron salts would occur which would hasten the hydrolysis and establish a new equilibrium. Consequently, river samples which are slightly alkaline and contain iron salts will not always be capable of stoichiometrically neutralizing samples which are already acid. Because of a lack of sufficient data it is impossible to calculate the exact result of mixing samples of this kind in terms of alkalinity or acidity. However, the present procedure is considered satisfactory for the practical purpose of presenting the results as it is the simplest for purposes of presentation and not believed to be greatly in error.

Mine Sealing vs. Flow Control - During the past few years there has been considerable mine sealing activity in West Virginia on the Monongahela watershed. At the same time the Tygart Dam has been constructed and operated to maintain increased low flows. Both of these activities have had a beneficial effect on the stream and any complete program of acid control will probably require the use of both control methods.

The essential difference in the operation of the two acid control methods is that mine sealing reduces the acid load throughout the year while flow control causes no acid reduction but simply stores water during periods when excess alkalinity is available and saves it for discharge during subsequent periods when acid conditions are serious. Reservoir operation may also smooth out objectionable day to day acid surges. Acid reduction by sealing may vary considerably from month to month and, as a rule, is more effective during the low-flow months.

As multipurpose use of a flood control reservoir involves no appreciable storage from one year to the next, it is safe to assume that such a reservoir will not change the total tons of acid discharge during the year. In other words, the reservoir stores the alkaline flow for later discharge during an acid period in the same year. This means that annual average tons of acid discharge can be plotted to show trends with the effect of storage dams eliminated.

In order to illustrate the effect of the two control methods, in simplified form, Figures Ac-6, Ac-7 and Ac-8 have been prepared. These figures are based on a stream whose weighted average daily quality is neutral and which approaches the quality of the Monongahela River about the year 1920, as measured by the methyl orange indicator. Figures Ac-6 and Ac-7 show identical effects of the two methods of control as far as reductions of peak acidity and acid days are concerned. Figure Ac-8 shows the effects of the two methods of control added together to eliminate acid conditions in the stream.

The principal point of difference illustrated by Figures Ac-6 and Ac-7 is that mine sealing reduced the weighted annual average acidity while reservoir operation equalizes the discharge of alkalinity. The principal point illustrated by Figure Ac-8 is that the effects of the two methods of control actually can be added together to correct situations where either method alone might not prove adequate.

The functions of the reservoir, as stated, are to equalize the flow of natural alkalinity available for acid neutralization and to eliminate day to day acid surges. However,

as a reservoir does not affect the weighted average quality of the discharge, no amount of reservoir operation can make an alkaline stream of one whose average quality is acid.

Mine sealing on the other hand can be used to attack practically any situation with some hope of restoring a stream to alkaline conditions. While mine sealing cannot be applied to acid from active workings, as can reservoir operation, it should be pointed out that probably not over 10 percent of the total acid load comes from working areas. A stream restored to average alkalinity by sealing operations may still suffer from acid surges for which a reservoir is needed. In general, the two methods of acid control supplement one another.

Flood Control Reservoirs - The discussion of flow control thus far has been based on the assumption that the reservoir has been operated solely for the control of acid. Under such circumstances, alkaline water is stored only when there is an excess or balance of alkalinity in the stream and is discharged whenever the stream becomes acid. When the primary purpose of a storage reservoir is flood control, such ideal operation is not always possible. Using the Tygart Reservoir as an example, the plan of operation is to hold the reservoir at a low level (El. 1010) for flood protection until about April 10 and to fill the reservoir to elevation 1094 from April 10 to about June 15, leaving a lesser capacity available for flood control during and after this period. From about July 1st to December, the reservoir is used to increase low flows leaving the reservoir at a low level at the end of the year for flood control. Figure Ac-9 shows Tygart Dam operation in 1939 together with the pool elevation guide line.

Tygart Dam has, without doubt, had a beneficial effect on the water supply of Morgantown, West Virginia, 50 miles below on the Monongahela River. However, the main storage takes place in April, May and June rather than during periods of excess alkalinity. Figure Ac-10 shows, as near as can readily be computed, the effect of Tygart Dam on the acidity of this supply by months from July, 1938, through 1940. This shows that during the six main storage months in this record, alkalinity was available within the storage requirements during three months but was not available during the other three months. Therefore, during these latter three months the acidity at Morgantown was actually increased by Tygart Dam operation. Against this, there were six months in the 30-month period when the acidity was decreased and during two of these, the acid was neutralized.

It is of interest that Tygart Valley waters were substantially reduced in acidity by mine sealing before the dam was put in operation, thus illustrating again how the two control methods supplement one another.

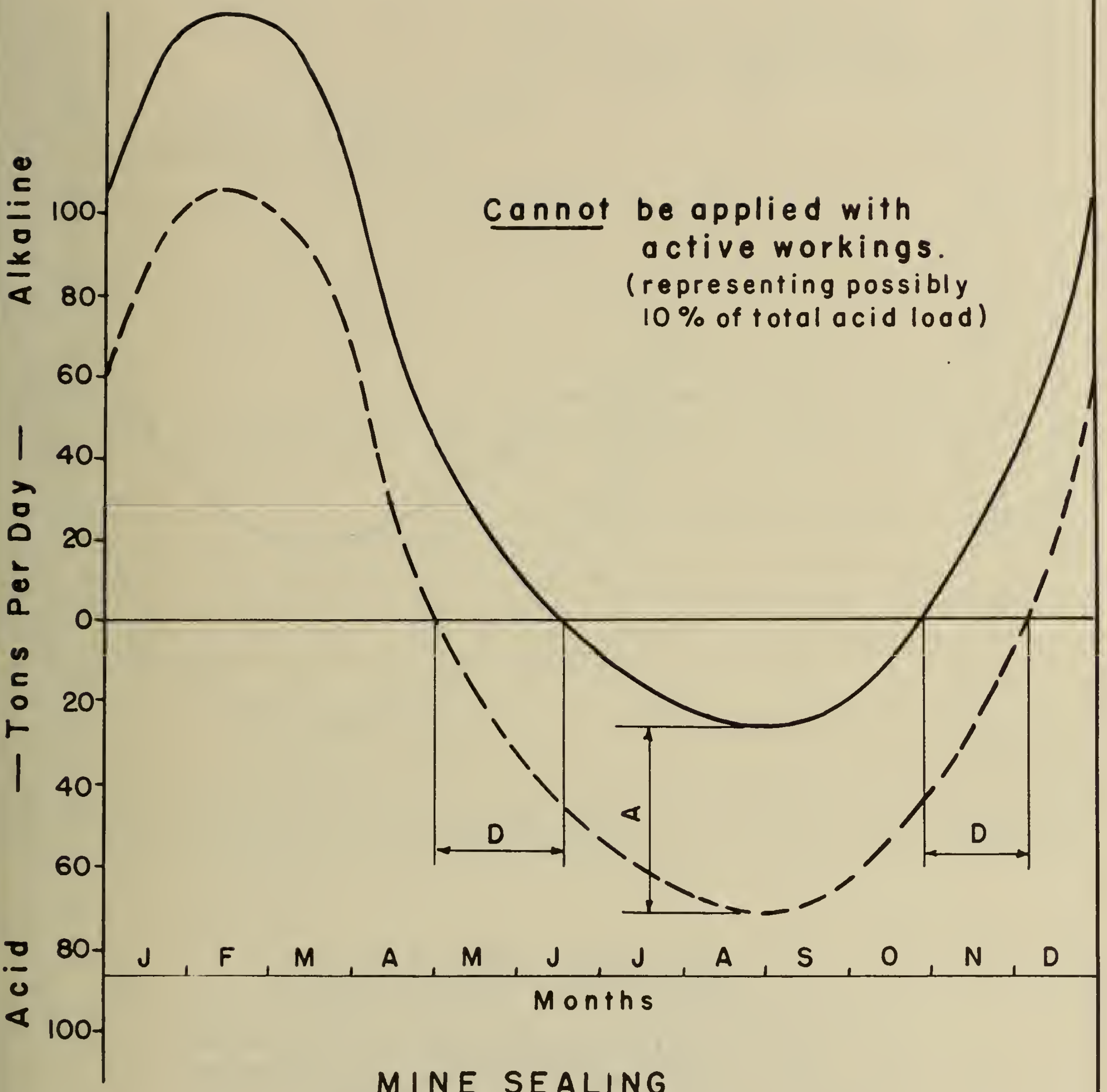
Neutralization - For many years consideration was given to abatement of the mine acid pollution problem by chemicals such as lime or limestone for neutralization. However, such treatment methods proved to be impractical due to the expense of operation and initial treatment plant construction. Estimates indicate that to treat all acid mine drainage in Pennsylvania, Maryland, Ohio and about half of West Virginia would require an initial plant investment of approximately $242,000,000, with annual operating costs of about $132,000,000. This annual operating cost compares favorably with the annual value of all the bituminous coal produced in Pennsylvania in recent years and amounts to an annual charge of about 50 to 60 cents per ton of coal produced yearly in the states named. For the entire United States the cost has been estimated at about $330,000,000 for plant construction with operating costs at $180,000,000 per year. No readily marketable by-products result from neutralization processes to help defray expense. In addition, the difficulty of disposing of the enormous amounts of iron and aluminum hydroxide sludge produced by neutralization is considered to be significant.

Miscellaneous Methods - A number of miscellaneous acid control methods have been used or suggested. One of these is an established policy of refraining from discharging acid waters to streams previously uncontaminated. In some cases this is highly desirable and the policy might be advantageously expanded in special cases.

Flooding or impounding is the natural result of discontinued pumping with abandonment of shaft mines. In other cases flooding appears dangerous and impractical, as well as being a poor substitute for mine sealing.

Regulation of mine openings and concentration of discharge has little over-all effect. A certain acreage of coal will be mined each year and the acid production will not be changed whether the coal is mined in new territory or old. Concentration of acid pollution brings about critical conditions. Dispersion may keep the acid within controllable limits.

Fig. Ac-6



MINE SEALING

- - - - Original acid-alkalinity curve.

—— Curve with mine sealing.

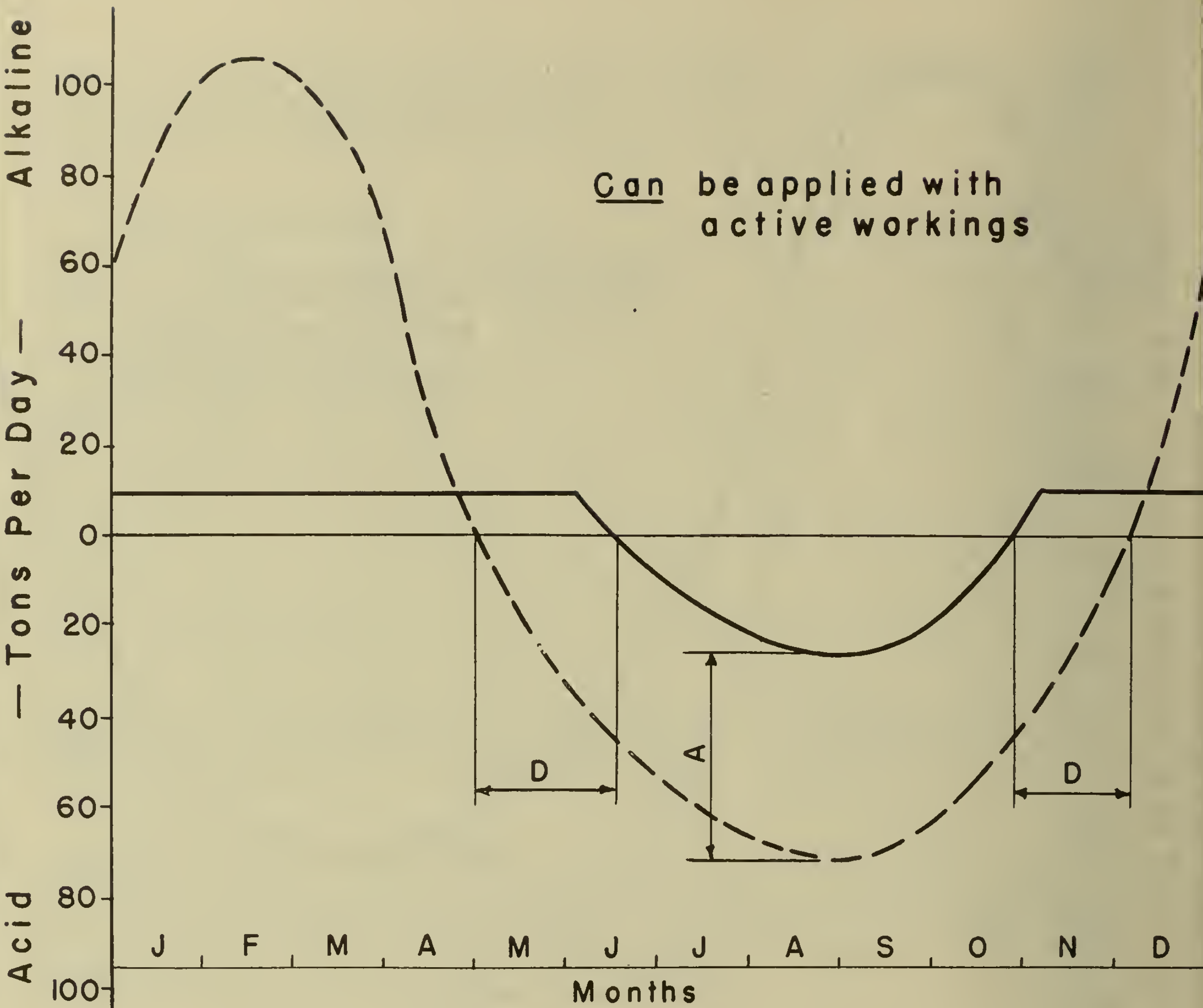
A --- Peak acidity reduced.

D --- Acid days reduced.

Weighted average annual acidity reduced.

U.S.P.H.S.
1941

Fig. Ac-7

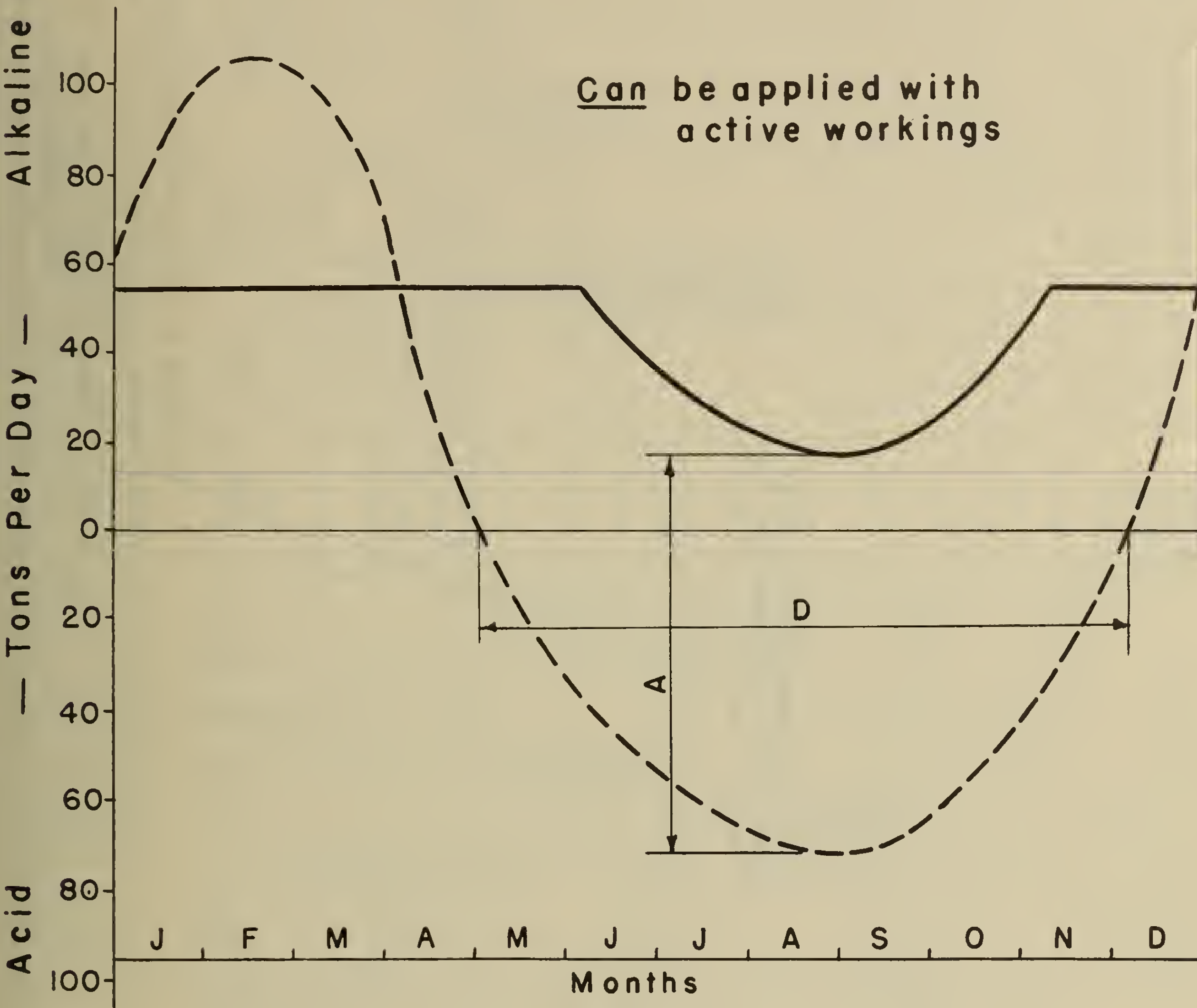


RESERVOIR OPERATION

– – – – Original acid-alkalinity curve.
——— Curve with reservoir operation.
A --- Peak acidity <u>reduced</u>.
D --- Acid days <u>reduced</u>.
Weighted average annual acidity <u>unchanged</u>.

U.S.P.H.S.
1941

Fig. Ac-8



COMPLETE PROGRAM

– – – – Original acid-alkalinity curve.

——— Curve with mine sealing plus reservoir operation.

A – – – Peak acidity converted to alkalinity.

D – – – Acid days eliminated.

Annual average acidity converted to alkalinity.

U.S.P.H.S.
1941

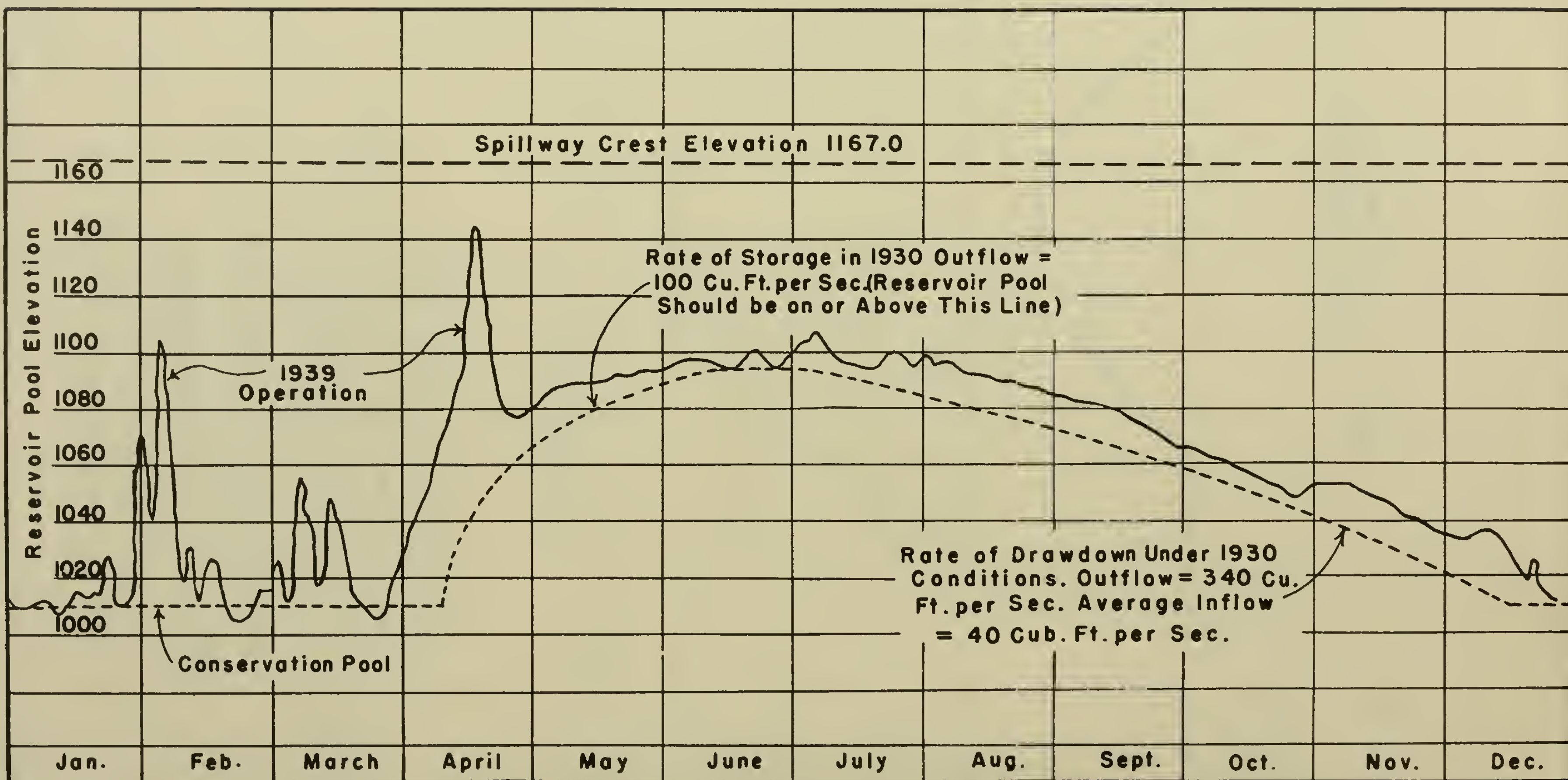
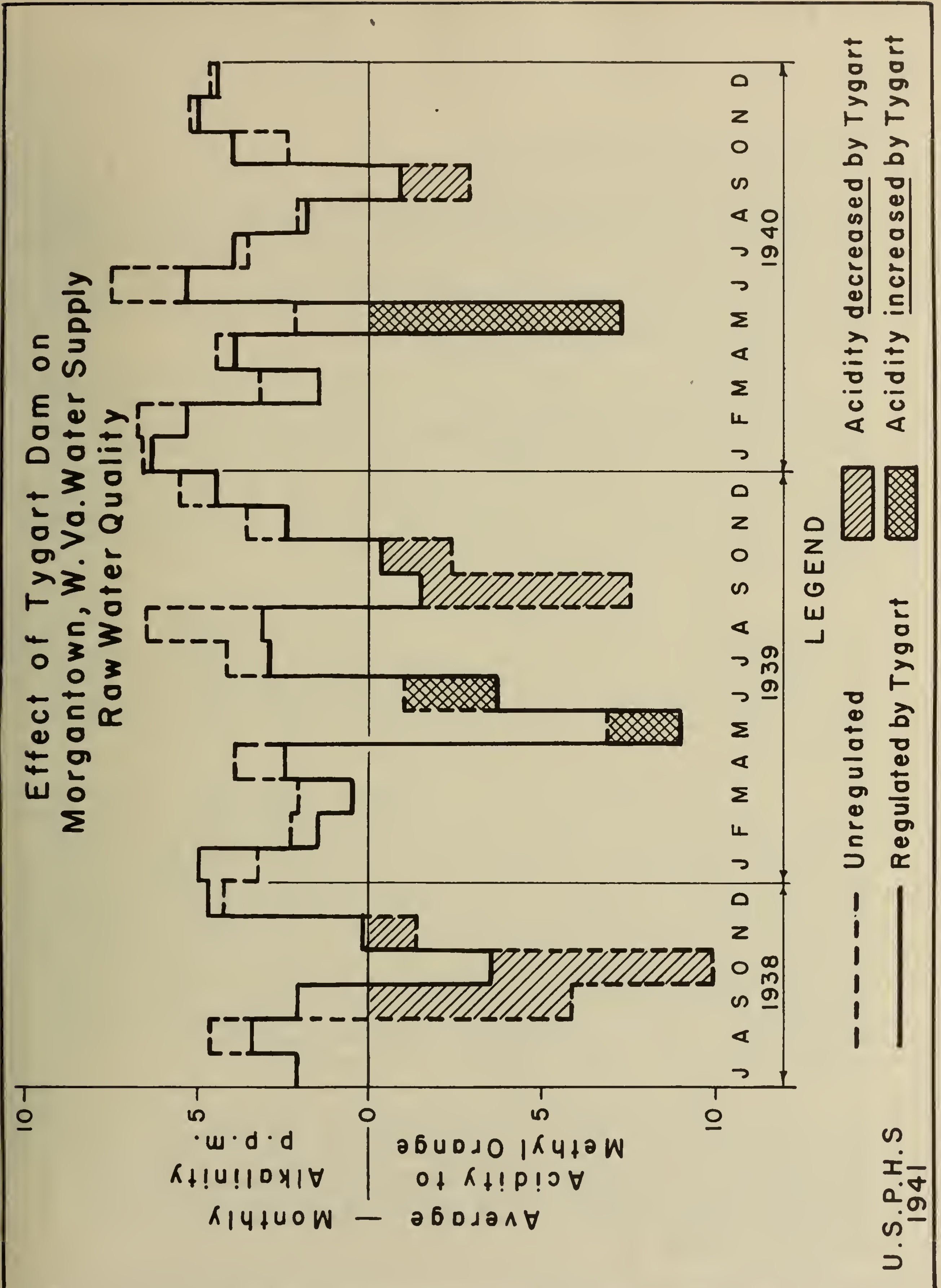


Fig. Ac-9

TYGART RESERVOIR OPERATION
POOL ELEVATIONS YEAR OF 1939
Data from U.S. Engineer Office
Pittsburgh, Pa.

U.S.P.H.S.-1941

Fig. Ac-10



Effect of Tygart Dam on
Morgantown, W. Va. Water Supply
Raw Water Quality
Average — Monthly
Acidity to Methyl Orange | Alkalinity p.p.m.
10
5
0
5
10
J A S O N D
1938
J F M A M J J A S O N D
1939
J F M A M J J A S O N D
1940
LEGEND
Unregulated
Regulated by Tygart
Acidity decreased by Tygart
Acidity increased by Tygart
U.S.P.H.S
1941

Statutes and Court Decisions

Legal efforts to control acid mine drainage through enactment of State laws or through court action have made little progress. Of the two legal approaches, court action has been the more successful. Ohio, Pennsylvania and West Virginia have laws specifically exempting mine drainage from control while in one instance, the Indian Creek case, court action was successful in obtaining relief.

Statutes - The mining laws of the states of the Ohio River Basin are administered by the State mining departments whose duties are to execute and enforce the State mine inspection laws, enacted for the safety of persons employed within or at the mines and the protection of mine property and other property used in connection therewith. It is the duty of the Chief Mine Inspector to report improvement of methods, conditions, development, and progress in mining with reference to health, safety, economy and conservation.

The States of Ohio, Pennsylvania and West Virginia have Sanitary Regulations pertaining to the disposal of sewage and industrial wastes but in these States acid mine drainage is exempt until treatment and/or disposal methods are developed. The mining laws of West Virginia provide that mine drainage waters be free from pollution by human and animal excrement or substance deleterious to health.

The mining laws of Kentucky, Tennessee, Virginia and West Virginia state that it is the duty of the mine foreman to remove water from working places within the mines. Alabama, Georgia, Illinois, Kentucky, Pennsylvania, and North Carolina provide regulations in their mining laws for eminent domain, that whenever any mine or ming place shall be so situated that it cannot be conveniently worked without a ditch to drain or convey water thereto, the owner or operator may construct such ditch when he complies with the law of eminent domain. The Kentucky law states, "the water so drained or pumped from such mines shall be drained as directly as practicable to adjacent streams or watercourse by means of ditches, flumes, pipes, sewers or other adequate provisions."

The Pennsylvania mining laws provide for the sealing of abandoned mines but do not prescribe the method. The laws of Indiana, Ohio and Virginia permit the sealing of worked-out sections of active mines while West Virginia does not prohibit this sealing. Ohio and other states provide for closing and/or fencing abandoned mine openings to prevent entrance thereto.

Table Ac-7 Acid Mine Drainage - Summary of State Mining Laws Pertaining to Acid Mine Drainage.

State	Mining Regulations providing for		
	Sealing of Abandoned Mines	Sealing of Abandoned Workings of Active Mines	Exempting Acid Mine Drainage from Regulation
Alabama	-	-	-
Georgia	-	-	-
Illinois	-	-	-
Indiana	-	Yes	-
Kentucky	-	-	-
Maryland	-	-	-
No. Carolina	-	-	-
Ohio	-	Yes	Yes
Pennsylvania	Yes	-	Yes
Tennessee	-	-	-
Virginia	-	Yes	-
W. Virginia	-	Not prohibited	Yes

Regulations of Alabama, Maryland, Pennsylvania and Virginia provide for the reopening of old and abandoned mines and for the drainage of water therein. All states have safety regulations governing the approach to abandoned mines or worked-out sections which may have dangerous accumulated water or gas.

Table Ac-7 summarizes the State laws on certain features of the acid mine drainage problem. In general, it appears that there are as many laws hindering the control of acid mine drainage as there are assisting this control.

Court Decisions - The two court decisions relating to acid mine drainage, the Indian Creek case and the Sanderson case, are basic in character and rather widely known. In the Indian Creek case, the Court found in favor of a water company as the water was considered more important to the Commonwealth than the coal. In the Sanderson case, the reverse was true, as the Court found in favor of the coal mines as the coal was considered more important. The following is, in part, from a published summary of a discussion of these two cases.

Indian Creek Case - The Mountain Water Supply Company was organized in 1905 and appropriated the water of Indian Creek to supply the Pennsylvania Railroad System in southwestern Pennsylvania, as far west as Pittsburgh. A large storage dam was built about 4 miles from the mouth of Indian Creek. The drainage area above this point is 110 square miles, of which 55 square miles were underlaid with the lower coal productive measures. In addition to supplying the Railroad Company, the Water Company furnished water to several municipalities in western Pennsylvania, supplying about 75,000 people. Active coal development began on a large scale, and it was apparent that this important water supply eventually would be damaged or destroyed if mining continued. The water company appealed to the Courts for an injunction to restrain the coal companies from discharging acid drainage into Indian Creek above the dam.

The Fayette County Court decided there was no public use of the water and that preventing the mining companies from discharging water into Indian Creek would deprive them of the use of their property. The court refused to grant an injunction restraining the mining companies from discharging mine water into this stream. The Pennsylvania Supreme Court reversed the lower court declaring that it was not a question of property rights, but that it was a nuisance to pollute the stream and that the mining companies should not, after a certain period, discharge the mine water into Indian Creek or

its tributaries above the dam of the water company. This opinion which was concurred in by the U. S. Supreme Court, states:

> "It is controlled by one fact and a single equitable principle; the fact that the stream has been polluted, and the principle that this creates an enjoinable nuisance if the public uses the water."

Sanderson Case - In 1886 Sanderson bought property in the City of Scranton through which flowed Meadow Brook, a pure, unpolluted stream. He built a dam and developed a water supply for his own use. About the same time Pennsylvania Coal Company opened a coal mine which soon produced acid mine drainage destroying the use of the brook water. Sanderson brought suit for damages resulting from loss of the stream. The case was twice tried in courts of Lackawanna County, Pennsylvania, and was twice before the Supreme Court of Pennsylvania. The Supreme Court decision affirmed the lower court's award of damages to Sanderson; Justice Paxon filed a strong dissenting opinion, which was sustained in the second Supreme Court decision.

The Court took the position that if Sanderson could collect damages every riparian owner thus affected could do likewise and if they could collect damages they could also enjoin the pollution of streams by mine drainage which would practically stop all mining operations except by consent of the lower riparian owners; that trifling inconvenience to particular persons must sometimes give way to the necessities of a great community, especially where the leading industrial interest of the state is involved. The court further stated in its opinion that the coal company was making the natural and ordinary use of its property, and that Sanderson with others was then securing an abundant supply of pure water from other sources, but that it would not say that a case "may not arise in which a stream, from such pollution, may not become a nuisance, and that the public interests as involved in the general health and well being of the community may not require the abatement of that nuisance."

The difference between the Sanderson and the Indian Creek decisions is that Sanderson, an individual who had access to another good supply of water, was not permitted to stand in the way of Pennsylvania's greatest industry whereas in the Indian Creek case the public, also represented by the Commonwealth, was fighting to preserve one of the last available pure water supplies in the state, and the decision merely carried out one of the principles enunciated in the Sanderson decision.

Presentation of Field Data

Mine Acid Loads

In collecting information on mine acid loads in the Ohio River Basin valuable assistance was furnished by the personnel of the Office of Mine Sealing. In certain cases, records were summarized from state files but in all cases the information was checked by Mine Sealing personnel familiar with the work in the various states. This personnel is of the opinion that certain portions of the load estimates are based on less than satisfactory complete data. However, it is agreed that the estimates are the best available and that improved estimates would require extensive sampling and gaging studies, neither possible nor justified, for the purpose of the Ohio River Pollution Survey.

Magnitude - Table Ac-1 indicates the magnitude of the acid mine drainage problem by states and major tributary basins in terms of tons of acid produced annually by active, marginal and abandoned mines, the estimated present status of the remedial measures of mine sealing and the estimated portion of the total acid load which may be removed economically by sealing methods under restrictions of 1940.

Figure Ac-2 shows, in graphical form, the magnitude of the original mine acid loads and the reduction by present and possible future economical mine sealing under 1940 restrictions in each state. As there are two distinct coal fields in Kentucky, one in the east and one in the west, two symbols have been used in this state, one for each coal field.

Intensity - The intensity of the acid load is given on Table Ac-1 in terms of tons per square mile per year. These figures show strikingly that the problem is acute in the areas drained by the Monongahela, Youghiogheny and Kiskiminetas Rivers and in the states of Pennsylvania and West Virginia. The loads given are prior to sealing and more recent residual loads are, in certain cases, much less.

Pickle Acid Comparison - Table Ac-8 presents a summary of mine acid loads (to phenolphthalein) in 1000 pounds per day and compares these figures with the free acid loads from waste pickle liquor. The pickle liquor free acid load shown as 3.4 percent of the present mine acid load does not include the iron salts which are probably hydrolized to some extent in solution to form sulphuric acid. This latter acid, which must

Table Ac-8 Acid Mine Drainage - Summary by Tributary Drainage Basins, of Original Mine Acid Loads and Mine Acid Loads after Present Sealing and Complete Sealing Program under 1940 Restrictions Together with Comparison with Waste Pickle Liquor Free Acid Loads.

Tributary Drainage Basin	Mine Acid Loads as $CaCO_3$			Free Acid Load from Pickle Liquor as $CaCO_3$ (1)	
		After Mine Sealing			
	Original	Present (A)	Complete Program		
	1,000 Pounds per Day				Percent of (A)
Alle. R. except Kiski.	456	355	177	17	4.8
Kiskiminetas River	1,764	1,703	975	10	.6
Allegheny River Total	2,220	2,058	1,152	27	1.3
Monon. except Yough.	3,841	2,461	1,827	57	2.3
Youghiogheny River	1,204	1,079	624	-	0
Monongahela River Total	5,045	3,540	2,451	57	1.6
Beaver River	95	83	47	64	77.
Little Kanawha River	4	2	2	0	0
Kanawha River	180	105	93	0	0
Guyandot River	111	60	52	0	0
Big Sandy River	334	253	153	0	0
Muskingum & Hocking Rivers	1,182	681	577	11	1.6
Scioto River	132	98	59	0	0
Little Miami River	0	0	0	0	0
Licking River	Slight	-	-	0	0
Miami River	0	0	0	55	-
Kentucky River	230	167	115	0	0
Salt River	0	0	0	0	0
Green River	419	336	210	0	0
Saline River	Slight	-	-	0	0
Tradewater River	43	39	21	0	0
Cumberland River	1,451	1,073	563	0	0
Tennessee River	209	120	61	0	0
Wabash River	600	343	176	2	0.6
Main Ohio River - Pa.	271	221	139	32	14.5
Ohio	622	486	266	31	6.4
W.Va.	147	97	87	48	49.5
Ky.	94	73	46	9	12.3
Ind.	72	38	36	-	0
Ill.	14	13	7	-	0
Main Ohio River Total	1,220	928	581	120	13.0
Unclassified - Virginia	103	103	42	-	-
Total Ohio River Basin	13,578	9,989	6,355	336	3.4
Percent Waste Pickle Liquor Acid-Mine Drainage Acid	2.4	3.4	5.3	-	-

(1) Does not include iron salts.

be included in any neutralizing plant, may vary from a minor item to 8 or 10 times the free acid load depending on the hydrolysis equilibrium. Acid pickle liquor wastes are important in local areas particularly in the vicinity of outfalls but they are less of a general problem than acid mine drainage.

Mine Sealing Costs

Table Ac-2 presents statewide and Ohio River Basin figures for the cost of mine sealing to date and cost estimated to complete a program of mine sealing under 1940 restrictions. The complete program mentioned here and in other discussions contemplates sealing all acid discharges that can be sealed for a cost not exceeding approximately ten dollars per ton per year. As pointed out in later discussions, this cost limitation can be extended and such extension appears justified.

Mine Acid Effects

Mine drainage, containing sulphuric acid and the acid salts (sulfates) of iron and aluminum, which reaches the surface streams in the bituminous coal mining areas in Pennsylvania, West Virginia, Maryland, Ohio, Indiana, Kentucky, Illinois and Virginia, is one of the most damaging industrial wastes in the Ohio River Basin. Pollution from this source is greatest in Pennsylvania and West Virginia, the two largest bituminous coal producing states. Unlike most damages caused by sewage and organic industrial wastes, most damages from acid mine drainage are real and tangible and can be estimated with a reasonable degree of accuracy.

The immediate effect of acid mine water on small and large streams is to change the chemical character of the water. More specifically, acid mine drainage will:

(1) Destroy or materially reduce the natural alkalinity resulting in conversion of carbonate to noncarbonate hardness.

(2) Lower the pH.

(3) Increase the total hardness.

(4) Add objectionable amounts of iron, manganese, aluminum and sulphate to the water.

These changes result in damages to the stream, both tangible and intangible. The tangible damages which have been evaluated are briefly as follows:

(1) The water is rendered expensive and difficult to treat for municipal and industrial use.

(2) The water is rendered highly corrosive to ordinary steel or iron structures and equipment such as culverts, bridges, locks, boat hulls, steel barges, pumps and condensers. Concrete structures are also damaged.

The intangible damages, which are nonetheless real and important, are briefly as follows:

(1) The streams are often rendered unsatisfactory for normal recreational use; i.e. fishing, boating, swimming.

(2) The biological processes and characteristics of the streams are substantially altered. Normal biological activity is retarded. In other words, the stream is no longer the habitat for desirable aquatic life.

(3) Chemical precipitation action of iron and aluminum salts, combined with the low velocity in the navigable channels, results in the heavy deposition of sewage solids particularly below Pittsburgh, and the ensuing flush-out by high water causes a wide fluctuation in quality, as reported by water plant operators, to pass down the Ohio River to the great detriment of public water supplies and hazard to the public health.

Acid mine drainage has served as a deterrent to the abatement of other types of pollution, particularly of an organic nature. There is no great incentive nor, in fact, justification for sewage treatment or the correction of organic industrial pollution if the result will be a stream that remains unsuitable for any use other than the disposal of mine waters. While other sections of the country have made substantial progress in the restoration of streams, the mining areas are notable for the few sewage treatment plants to be found.

The germicidal, inhibiting and other effects of the acid may prevent odor nuisance, a point which has been the subject of considerable discussion. However, the visual nuisance may

remain and from a public health standpoint or in the protection of public water supplies, acid mine drainage is not a dependable safeguard. During a freshet the rapid increase in flow may bring sufficient alkalinity to neutralize the acidity and eliminate the germicidal effect. This would happen at the same time that accumulated sludge deposits are being flushed out and the greatest need for a germicidal effect occurs. A water plant depending on acid mine drainage germicidal action would be operating under a greatly reduced factor of safety.

Evaluation of Damages

Damages caused by acid mine drainage differ from most damages caused by organic pollution in that many of them have a definite quality and are capable of accurate determination in dollars. While damages due to impaired recreation, the creation of a nuisance and hazard to the public health are equally real and important, a monetary estimate of the extent of such damages must be based on assumptions of the person making the estimate. No assumptions are necessary to determine the cost of chemicals for neutralizing a raw water or removing noncarbonate hardness. The cost of removing a barge or towboat from service for extra painting and the cost of that painting can be determined with accuracy.

The damages considered in this section are confined to those capable of definite and accurate estimation in dollars, A summary of the damages estimated is given in Table Ac-3. Damages to river and harbor structures and to the floating plant of the U. S. Engineer Department are based on the years from 1937 to 1939 inclusive and corrected to the year 1940. All other damages are based on average experience during the past ten years and corrected to 1940.

The damages shown on Table Ac-3 for 1940, 1950 and 1960 are all based on 1940 use or on present navigation activity, water supply pumping and other items. The 1960 estimate might well be increased from 25 to 50 percent to include an increment of increased use that is a normal expectancy.

Information for the evaluation of damages by acid mine drainage were collected, in part, during the regular industrial and municipal field investigations and in part by the special staff assigned to the acid mine drainage problem. Knowledge and appreciation of the damages are quite general, but carefully assembled reliable data on the extent of damages in dollars were available in only a small percentage of cases.

However, these relatively few cases were such that unit factors could be determined and applied in other locations with adjustments for the size of the establishment and the severity of the acid problem. Supporting data are too voluminous for inclusion in this supplement. In general, the methods used are as follows:

Water Supplies - Damages to water supplies consist of first, the cost of chemicals required to neutralize the free mineral acids and at least part of the acid salts and, second, the chemicals required to convert noncarbonate hardness caused by acid mine drainage back into its original carbonate form. Lime is needed for domestic, boiler and industrial cooling waters to neutralize the acidity. Soda ash is needed to convert the noncarbonate hardness in the domestic and boiler waters only.

The quantities of water used for domestic and industrial purposes were taken from the field survey reports. Information on raw water quality for the past ten years was obtained from water plant records. Particular emphasis was placed on the records of the McKeesport water plant on Monongahela River water and on the records of the Pittsburgh filter plant at Aspinwall on Allegheny River water.

Neutralization is necessary to prevent corrosion or reduce it to a normal condition that would exist in the absence of acid mine drainage. Neutralization of the free mineral acids or the acidity to methyl orange would leave a water with pH 4.0. This is lower than normal and would still cause excessive corrosion. To raise the pH above 4.0, part of the acid salts must be neutralized. Lime requirements for neutralization have been based on raising the pH to an approximate 7.0 or the neutral point. As the water plant records do not give information directly on the daily quantities of chemical required for this purpose, it has been determined on the basis of long time averages that Monongahela River water at McKeesport above the mouth of Youghiogheny River having a pH of 7.0 will have a methyl orange alkalinity of 14 p.p.m. and a phenolphthalein acidity of 5 p.p.m. Similarly, Allegheny River water at the Pittsburgh intake at Aspinwall having a pH of 7.0 will also have a methyl red alkalinity of 14 p.p.m. Neutralization costs were based on adding sufficient lime to bring the waters up to the alkalinities stated. On days when the alkalinity was above these values it was assumed that no lime was needed.

All of the original acid load as measured by phenolphthalein will be represented by noncarbonate hardness. That part of the acid load neutralized by natural alkalinity will convert carbonate hardness to noncarbonate hardness. That part of the acid load neutralized by lime will also convert the carbonate hardness added by the lime to noncarbonate hardness.

The mean p.p.m. total acid concentration as $CaCO_3$ was computed by applying the original acid loads as given in Table Ac-2 to the average flow in the various streams. As explained, this acid will be represented by noncarbonate hardness and will require soda ash for removal in the domestic and boiler waters.

Steamboats and Barges - River transport equipment suffers slight to severe damage as a result of corrosion of boilers, hulls, pipes, and pumping facilities. Besides corrosion difficulties, scale and sludge formation in boilers, with accompanying poor heat transfer and increased blow-down, and time out of service cause added operating difficulty and expense.

Managers of transportation companies were interviewed and asked for data on damages resulting from acid in the streams. This information was broken down into boiler replacements, boiler cleaning, repairs to hulls, replacements of pumps and pipes, loss of revenue while out of service, and the maintenance of barges. Average cost per boat or barge for the above items was computed. The Pittsburgh office of the U. S. Engineer Department furnished information on the number of boats and barges operating in the district. The annual damages were then computed from the average figures and the numbers of vessels.

Power Plants - The quantities of cooling water used by power plants are very high and neutralization of this water is not practical. In general, water is used without neutralization and equipment is replaced when made necessary by corrosion.

Before making estimates of damages to power plants, many plant superintendents were interviewed and data obtained as to the frequency and cost of replacements and the portion attributable to corrosion. Consideration was given to such factors as average acidity of the water, type of metal used, length of service, time lost by shutdowns and labor costs.

The power plants were grouped by localities and estimates made of damages per unit of capacity for each group. Total damages were then readily computed.

The fact that power plants practice repair and replacement of equipment rather than neutralization of acidity in cooling water is evidence that repair and replacement is the more economical procedure. As a check, the cost to power plants of neutralizing cooling water was computed on the same basis as was the cost to municipal and industrial water supply. Neutralization cost was found to be $261,000 per year as compared to $76,000 for repairs and replacements due to corrosion. This would confirm the wisdom of power plants in not attempting to neutralize cooling water.

River and Harbor Structures - Acid pollution results in damage by corrosion to locks, dams and other appurtenances. This corrosion is accelerated to some extent by the erosive action of the water, which keeps the exposed surfaces clean and damages protective coatings. Since the U. S. Engineer Department is repsonsible for the construction, operation, and maintenance of these structures, the officials concerned were interviewed and asked for an estimate of the annual damages. The figure is based mainly upon experience in regard to average frequency of repairs and replacements.

Floating Plant (U.S.E.D.) - An estimate of damages to their floating plant was furnished by the U. S. Engineer Department.

Other Damges - Damages which are important but for which no detailed estimates have been made include (1) damage to water supply caused by the presence of manganese, (2) damage to recreation through the destruction of normal aquatic life, (3) damage to agricultural uses, (4) damage to highway structures, (5) damage to the mines themselves and (6) the previously mentioned indeterminate but serious damage to the public health.

Manganese is present in acid mine drainage streams but field investigations did not yield information indicating damage of great consequence. Sand filter plants remove the greater part of the manganese without special provisions.

Damage to recreation is an item of great consequence. The Allegheny Reservoir report of the U. S. Engineer Department estimates benefits to recreation from Allegheny Reservoir (reservoir full elevation 1365) equal to $300,000 per year due chiefly to the effect of this reservoir in reducing and eliminating the acidity. Neither the existence nor the magnitude of these benefits, which represent the correction of damages, can be denied but the various methods proposed for the evaluation of recreation facilities are all open to some question.

Damage to agricultural uses include destruction of a water supply used for stock watering or other purposes, damage to inundated land during high water and damage due to destruction of crop growing ability of land by seepage from a mine, as at an outcrop.

Considerable damage results yearly to bridges, culverts, drains and other highway structures from the acid waters. State officials generally agree that acid mine drainage causes considerable added expense each year, but no specific records are available. Replacements have been greatly reduced in recent years by building structures having stone or brick facing and by using a bituminous coated pipe on streams carrying mine drainage.

Damage to the mines themselves is definitely a factor. There are instances of record of a mining company finding it necessary to go a matter of several miles for a satisfactory water supply at the same time that acid water was available in quantity from its mine. In one case, power was purchased even though usable but unmarketable coal was available. An almost universal source of damage is the corrosion of metal work, especially pumps and pipe lines connected with drainage system. A mine may well find it distinctly profitable to seal worked out sections of its active mine in order to decrease damage to pumps, pipe lines and other metal work and to provide an improved water supply. The savings in ventilation have been mentioned.

Some of these damages are capable of evaluation but either time has not been available or expenditures necessary have not been deemed justified. Other damages have not been evaluated either because of the lack of available long-range data or because of the indeterminate nature of the damage.

Although as stated, no estimate has been made of the magnitdue in dollars of the miscellaneous and intangible damages discussed, it may be reasonable to assume that these damages are probably equal to the tangible damages for which estimates have been made.

A clean or unpolluted stream is an extremely difficult item to evaluate. The value depends not only upon monetary considerations which can be estimated with a degree of accuracy but also upon the popular demand and the relative urgency of this demand as compared to other demands upon public and private funds.

An indication of the value of clean streams is shown in the actual expenditures in other areas for the correction of polluted conditions caused by sewage and organic wastes. Statewide averages for pollution abatement programs on tributary streams have been in the neighborhood of from $25,000 to $75,000 per mile of stream improved, the variation depending upon the size of stream, magnitude of the pollution problems and degree of treatment required. Costs on a main stream such as the Ohio River would be much higher than these figures.

Presentation of Laboratory Data

The presentation of the detailed laboratory data collected during the course of the Ohio River Pollution Survey is included in the individual drainage basin presentations to which they apply. These data define the extent of the acid mine drainage problem and show in terms of analytical results the effect of acid mine drainage on Ohio River Basin streams. Figure A-5b and Mo-5a taken from the main volumes of the Final Report of the Ohio River Pollution Survey show the extent of acid mine drainage effects as indicated by pH results on stream water samples on the Allegheny and Monongahela River basins respectively.

In addition to the routine sampling at all important points on the Ohio River Basin, a laboratory unit stationed at Morgantown, West Virginia from late in July, 1940 to the end of June, 1941 performed work relative to the effects of coal mine acid on specific streams. This work is the subject of a separate, special report.

Water Plant Records

The raw water analytical records collected over a period of years by the water plants using river water furnish a valuable source of material for a study of the increasing effect of acid mine drainage during the development of the coal mining industry. With the help of these records, a general long time trend can be established and estimates of future conditions can be made.

As was discussed earlier, if computations of annual average discharges of acid in tons are made, the effect of storage reservoirs that store and release water during the same year is eliminated. Accordingly, water plant records were converted into annual average tons of acidity (or alkalinity) and the results plotted for the period of record. Figures Ac-10 and Ac-11 were prepared in this manner. Mass diagrams of total coal production were plotted on the same graph using a scale selected such that the resulting curve serves as a trend line for the acidity curve. On the Allegheny curve, Figure Ac-10, sulphates are also plotted, since results of this determination were available. Mine acid loads, with expected reductions by sealing, have been plotted on a parallel scale.

Fig. A-5b

ALLEGHENY BASIN

pH RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Fig. Mo-5a

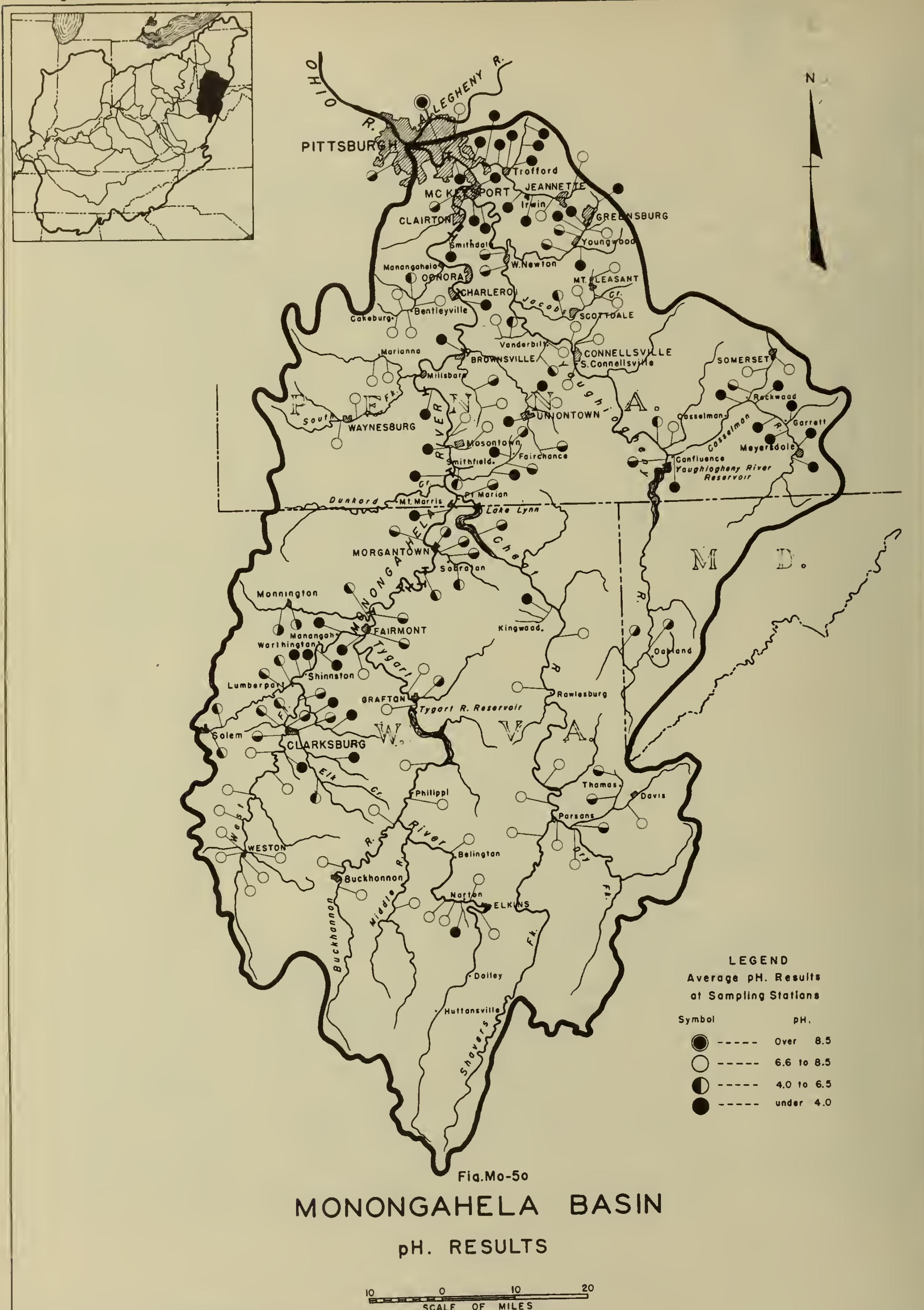


Fig. Mo-5a

MONONGAHELA BASIN

pH. RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Discussion

This report has covered the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Estimates have been presented of the total acid load, the reduction in this load to date and possible future economical reduction by mine sealing under 1940 restrictions. Costs of this program to date and estimates of future cost are given. Damages have been enumerated, discussed and evaluated.

A consideration which should be mentioned early and kept in mind constantly is that the acid mine drainage problem has been constantly growing and there is little reason to believe that this growth will not continue. The acid mine drainage was no great problem in 1900 but by 1910 it had made itself felt. By 1920 the Kiskiminetas and Youghiogheny Rivers had been acid for some time and the average quality of the Monongahela River above the Youghiogheny was soon to become acid. Since then the problem has become progressively worse and in the high acid year of 1934, the Allegheny River barely missed becoming acid in average quality. By 1955, at the present rate, the Allegheny River may easily have an average acid quality during a normal year.

Damages caused by acid mine drainage have been evaluated for the period from 1930 to 1940. During the next decade, unless corrective measures are actively pursued, these damages will continue their trend upward as the natural alkalinity of the principal streams becomes exhausted. As shown on Table Ac-3, an increase in damages estimated at 50 percent may be expected by 1960.

Remedial Program

A primary purpose of the acid mine drainage study has been to secure basic data on which to base a comprehensive remedial program. The program, as presented, involves mine sealing and flow regulation from storage reservoirs. The program is not the ultimate possible as the mine sealing discussed goes only as far as permitted by 1940 restrictions. However, a large step is involved and upon its completion, additional knowledge should be available in planning further corrective measures.

The studies indicate definitely that the Allegheny River can be brought back to substantially satisfactory condition and this might well be a first objective of a remedial program. Although less detailed studies have been made, it appears likely that many of the headwater streams of the Youghiogheny and Monongahela Rivers can be returned to satisfactory conditions and might well also be included as first objectives.

The Monongahela River above the Youghiogheny River can be greatly improved but, without going somewhat farther than the present restricted program, present indications are that it cannot be brought back to the extent possible on the Allegheny River. There are two reasons for this: first, the original acid intensity in tons per square mile as shown on Table Ac-1 is about four times as great as on the Allegheny River and second, the normal upland water alkalinity (about 10 p.p.m.) is much less than that on the Allegheny River Basin (about 25 p.p.m.). However, against this, the damages caused by acid in the Monongahela River are very high due to extensive use for navigation and water supply and the possible monetary benefits from improvement of the stream are correspondingly greater. Because of this factor, the Monongahela Basin, especially above the Youghiogheny River, is a particularly fitting area on which to concentrate first in carrying out more advanced mine sealing beyond 1940 restrictions.

With the Allegheny River, certain upland streams and finally the Monongahela River above the Youghiogheny River in good condition, it is probable that the main Ohio River will return to satisfactory alkaline quality. Even partial correction of Monongahela River acid, when combined with a satisfactory Allegheny River, might accomplish this objective.

Restoration of the Monongahela River below the mouth of the Youghiogheny River will come much later as it will probably require a substantial alkalinity from above the Youghiogheny River.

There remains the question of the Kiskiminetas and lower Youghiogheny Rivers, where present mining and the acid mine drainage problem are concentrated. Much of the acid comes from active mines. This source is normally the last to be attacked and such attack must be confined to worked-out sections. It is probable that these two stream sections will not be completely returned to satisfactory quality until concentrated active mining moves, at least in part, to other areas.

In summary, it appears that the upper Ohio River and tributaries can best be returned to satisfactory alkaline quality in the following order:

(1) Allegheny River except the Kiskiminetas River
(2) Headwater streams, including the upper Youghiogheny
(3) Monongahela River above the Youghiogheny River
(4) Main Ohio River
(5) Monongahela River below the Youghiogheny River
(6) Lower Youghiogheny River
(7) Kiskiminetas River.

The following discussions of the Allegheny and Monongahela Rivers cover a remedial program involving two types of corrective measures, namely, mine sealing and flow regulation. An estimate of the part each of these measures plays in the total improvement will depend upon which remedial measure is placed in operation first and the first measure will make the more impressive showing.

As a practical approach, the effects of the two remedial measures have been considered on a basis of monthly averages. One effect of reservoir operation will be to reduce or possibly eliminate day-to-day acid surges which create serious water plant operation problems and may render an otherwise satisfactory stream unfit for fish life. Flow regulation benefits, in this respect, will not generally appear in a consideration of monthly averages. Thus one of the important features of flow regulation will not appear as a benefit. Considered from another standpoint, the benefits from mine sealing will be more fully realized if reservoirs for flow regulation are provided.

Conversely, the benefits from reservoir operation may depend, to a large extent, on mine sealing. The Tygart Dam already mentioned, is an example where an acid stream was rendered alkaline, a reservoir was constructed and improvements resulted which no single remedial measure could have accomplished.

This discussion leads to a conclusion that if a complete program involving the two types of control measures is justified, the individual parts are justified. For this reason acid control benefits have been lumped in one figure. This means, in effect, that parts of the mine sealing benefits, as computed from monthly averages, are assigned to flow regulation.

Allegheny River

Records are available on the quality of Allegheny River water at the intake of the Pittsburgh filter plant at Aspinwall from 1909 to date. Average annual alkalinity (to methyl red) and sulphate results in tons and cumulative coal production have been plotted on Figure Ac-11. It is to be noted that the average annual results are subject to wide variations. Several times in the past there apparently have been periods of four or more years during which there has been a definite beneficial trend toward increased alkalinity. Each time there has been a following adverse period so that the general long-time trend has been toward decreased alkalinity.

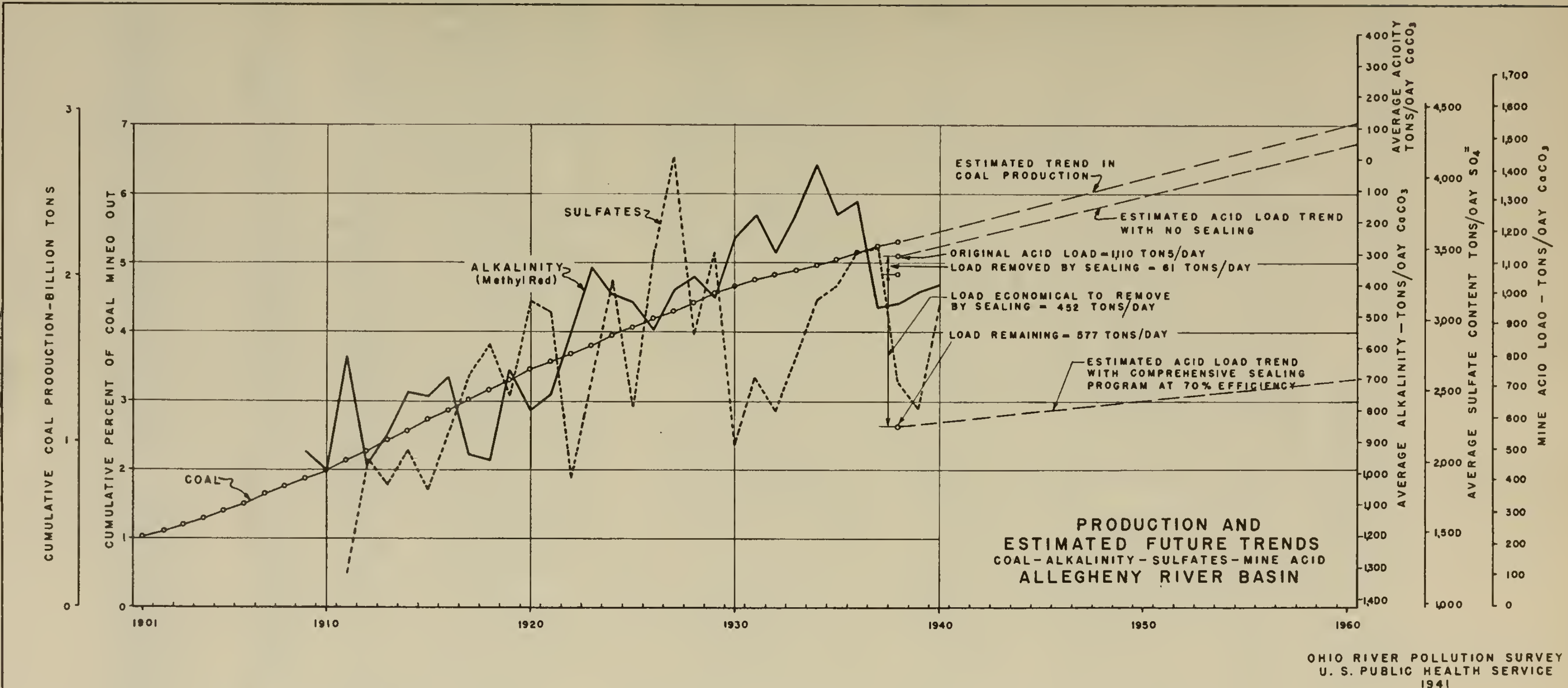
If the curve of cumulative coal production as shown on Figure Ac-11 does, in fact, show the trend of alkalinity and sulphates, the natural alkalinity and sulphate content of Allegheny River water prior to the development of the coal industry were 1400 and 1000 tons per day respectively. The average flow of the Allegheny River at Aspinwall from 1909 to 1940 inclusive was 20,400 c.f.s. Assuming equal distribution of alkalinity and sulphates in the average flow, a natural alkalinity of 25 p.p.m. and natural sulphate content of 18 p.p.m. are indicated.

The average alkalinity of Allegheny River water in 1909 actually was 25 p.p.m. The lowest average annual sulphate result was 36 p.p.m. obtained in 1911, the first year of sulphate record. However, on several occasions average monthly sulphate results of 18 p.p.m. were obtained during the early years of record.

As compared to these old results, the Allegheny River at Aspinwall had an average acidity of 5 p.p.m. in 1934 although in tons, or a weighted average, as plotted on Figure Ac-11, the average quality was alkaline. During that same year sulphates averaged 107 p.p.m. and on seven occasions the average annual sulphates have exceeded 90 p.p.m.

There has been a definite downward trend or an increase in alkalinity since 1934. This year coincided closely with the start of mine sealing activities. While part of the favorable trend may be due to mine sealing activities, there is apparently an additional trend due to a normal cycle followed by the alkalinity curve. In 1934 the average annual alkalinity was 12 tons (to methyl red) per day and the 1940 average was 407 tons per day, an increase of 395 tons per day. Mine sealing records indicate an acid reduction of only 81 tons

Fig. Ac-11


PRODUCTION AND
ESTIMATED FUTURE TRENDS
COAL-ALKALINITY-SULFATES-MINE ACID
ALLEGHENY RIVER BASIN
CUMULATIVE COAL PRODUCTION-BILLION TONS
CUMULATIVE PERCENT OF COAL MINED OUT
AVERAGE ACIDITY TONS/DAY CaCO3
AVERAGE ALKALINITY—TONS/DAY CaCO3
AVERAGE SULFATE CONTENT TONS/DAY SO4
MINE ACID LOAD - TONS/DAY CaCO3
COAL
SULFATES
ALKALINITY (Methyl Red)
ESTIMATED TREND IN COAL PRODUCTION
ESTIMATED ACID LOAD TREND WITH NO SEALING
ORIGINAL ACID LOAD = 1,110 TONS/DAY
LOAD REMOVED BY SEALING = 61 TONS/DAY
LOAD ECONOMICAL TO REMOVE BY SEALING = 452 TONS/DAY
LOAD REMAINING = 577 TONS/DAY
ESTIMATED ACID LOAD TREND WITH COMPREHENSIVE SEALING PROGRAM AT 70% EFFICIENCY
1901
1910
1920
1930
1940
1950
1960
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

(to phenolphthalein) per day which would not account for the great increase in alkalinity.

Mine Sealing - A principal purpose of plotting alkalinity, coal production and estimated acid load curves on parallel scales is to serve as a basis for estimating possible accomplishments by mine sealing. The coal production curve appears to be a true trend curve as it parallels lines drawn between successive peaks and successive low points and, in general, follows the course of the alkalinity curve. As the mine acid loads are plotted in parallel, it is not unreasonable to assume that completion of the mine sealing program would drop the trend line to a line representing "estimated acid load trend with comprehensive sealing program of 70 percent efficiency." The ordinate of this latter curve for 1940 approximates the ordinate of the coal production trend line for 1915. This would indicate that a comprehensive sealing program would return the Allegheny River to its 1915 condition.

If all mined-out areas that have developed since 1915 were, in some manner, eliminated as sources of acid pollution, it is to be expected that the acid mine drainage problem would revert to conditions as of that date. A comprehensive mine sealing program is estimated to remove the influence of the equivalent of all mined-out areas developed since 1915. It is, therefore, reasonable to conclude that a comprehensive mine sealing program would return the Allegheny River to its condition in 1915.

The maximum monthly acidity in the Allegheny River in recent years was 23 parts per million. This can be reduced in part by mine sealing and in part by a flow regulation program. The estimated result of the combined program is a conversion of the maximum monthly acidity of 23 parts per million to a minimum monthly alkalinity of 13 parts per million or an improvement of 36 parts per million. On an equitable basis, mine sealing can be credited with an improvement of 22 parts per million in the maximum monthly acidity. Improvement in the average quality would be much less.

Reduction in the Allegheny River acid should result in a lesser but important reduction in Ohio River acidity.

Flow Regulation - The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity in the Allegheny River but there will still remain

acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage.

A flow regulation program is suggested involving storage in a reservoir or reservoirs of 210,000 acre-feet capacity. On an equitable basis, this flow regulation can be credited with a 14 part per million improvement in the maximum monthly acidity, and a lesser improvement in the Ohio River. More stabilized flow will furnish partial protection against acid surges.

The Kiskiminetas River, entering the Allegheny River in its lower reaches, drains a concentrated mining area and is, therefore nearly always acid. Local rains in the area result in serious acid discharges into the Allegheny River and local storage will be required to combat the damages by discharging alkaline water to neutralize the acid surge. Upland storage is of little value in this case as the damage would be done and the danger over by the time water from such storage arrived. Therefore, any reservoir program on the Allegheny River for acid control will require limited local supplementary storage, as behind a local navigation dam provided with proper regulating devices.

The objective and principal features in the operation of the flow control program presented are as follows:

(1) The objective of the program is to maintain, as nearly as possible, a minimum alkalinity of 13 p.p.m. rather than secure the greatest monetary benefits from acid and hardness control. Such an objective tends to protect aquatic life.

(2) Storage is assumed to take place only during months when the alkalinity at Aspinwall is above 13 p.p.m.

(3) The quantity of water assumed to be stored is never such as to reduce the alkalinity at Aspinwall to a concentration below 13 p.p.m.

(4) Unregulated flows are increased as necessary to increase the alkalinity to 13 p.p.m. up to a maximum of the average flow of the stream or 20,400 second-feet.

(5) No attempt is made to increase alkalinity during months when the flow is in excess of the average of 20,400 second-feet. However, no water is stored during such months as such a procedure would further decrease the low alkalinity.

(6) The reservoir or reservoirs are assumed to be emptied each year. This feature and limitation in the amount of water that can be stored under the above restrictions governs the reservoir capacity suggested.

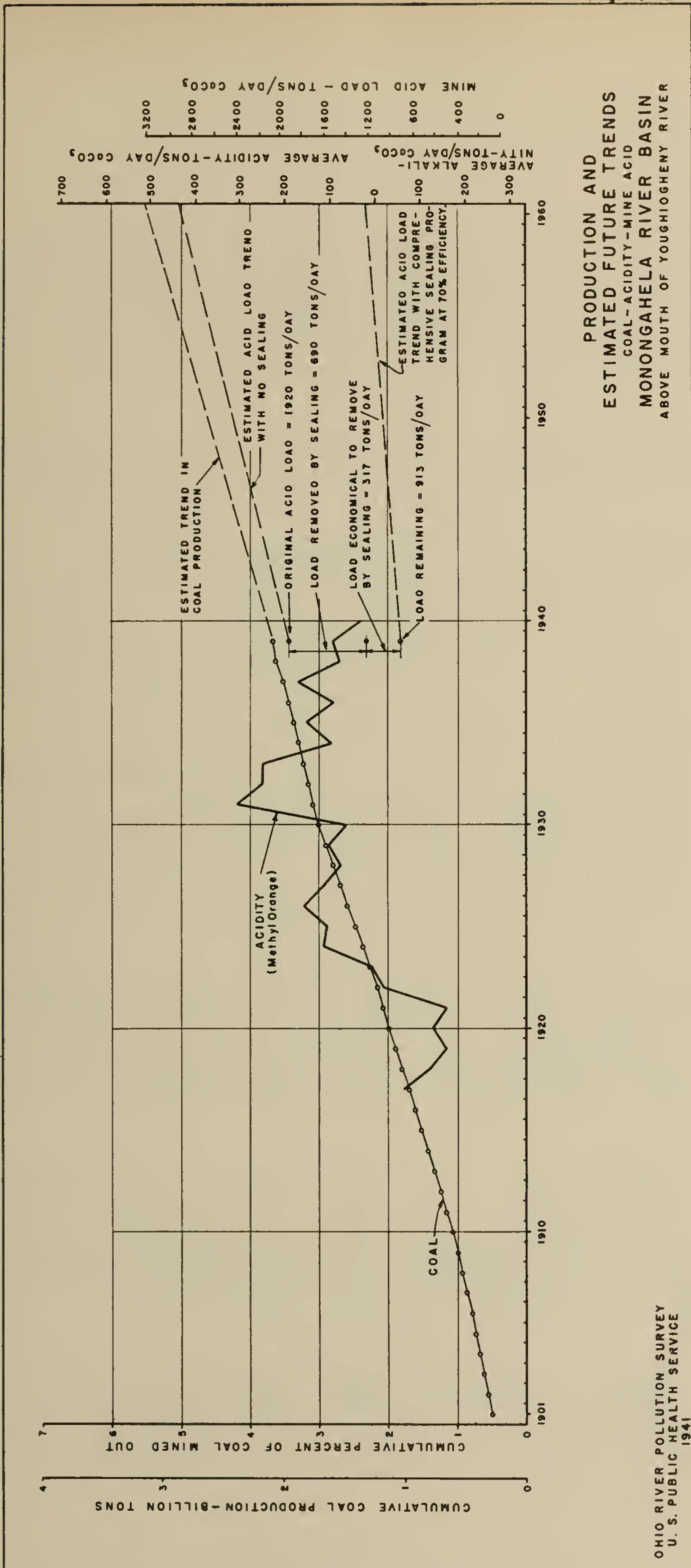
Monongahela River

Records are available on the quality of Monongahela River water above the mouth of the Youghiogheny River at the intake of the McKeesport water plant from 1917 to date. Average annual acidity (or alkalinity) results in tons and cumulative coal production have been plotted on Figure Ac-12. As noted on the Allegheny River curve, the average annual acid results are subject to wide variations. However, the general trend, especially prior to the last few years, has been toward an ever increasing acidity.

If the curve of cumulative coal production as shown on Figure Ac-12 does, in fact, show the trend of acidity, the natural alkalinity of Monongahela River water prior to the discharge of acid mine drainage was 300 tons per day. The average flow of the Monongahela River above the Youghiogheny River from 1917 to 1940 inclusive was 10,950 c.f.s. Assuming equal distribution of the alkalinity in the average flow, a natural alkalinity of 10 p.p.m. is indicated. During the early years of analytical record the Monongahela River above McKeesport was alkaline most of the time and as late as 1918 one monthly alkalinity of 8 p.p.m. was recorded.

As compared to this former quality, the Monongahela River above McKeesport had an average annual acidity of 16 p.p.m. in 1930, has had average annual acidities of 10 p.p.m. or more on nine occasions and has had an average quality acid to methyl orange every year since 1922.

During the past decade, or since 1931, there has been a marked decrease in the acid concentration of the Monongahela River. While most of the decrease has been during the comprehensive mine sealing program in the State of West Virginia, it has also been during a period of decreased mining activity, the construction of Tygart Dam and during a normal cycle as indicated by the corresponding Allegheny River curve. It is


PRODUCTION AND
ESTIMATED FUTURE TRENDS
COAL-ACIDITY-MINE ACID
MONONGAHELA RIVER BASIN
ABOVE MOUTH OF YOUGHIOGHENY RIVER
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941
MINE ACID LOAD - TONS/DAY $CaCO_3$
AVERAGE ACIDITY - TONS/DAY $CaCO_3$
AVERAGE ALKALINITY-TONS/DAY $CaCO_3$
CUMULATIVE PERCENT OF COAL MINED OUT
CUMULATIVE COAL PRODUCTION - BILLION TONS
ESTIMATED TREND IN COAL PRODUCTION
ESTIMATED ACID LOAD TREND WITH NO SEALING
ORIGINAL ACID LOAD = 1920 TONS/DAY
LOAD REMOVED BY SEALING = 690 TONS/DAY
LOAD ECONOMICAL TO REMOVE BY SEALING = 317 TONS/DAY
LOAD REMAINING = 913 TONS/DAY
ESTIMATED ACID LOAD TREND WITH COMPREHENSIVE SEALING PROGRAM AT 70% EFFICIENCY
ACIDITY (Methyl Orange)
COAL
1901
1910
1920
1930
1940
1950
1960

undoubtedly true that at least part of the favorable trend is due to mine sealing activities. In 1931, the average annual acidity was 312 tons (to methyl orange) while in 1940 it was 33 tons per day, a reduction of 279 tons per day. Mine sealing records indicate an acid reduction of 690 tons per day but this is measured as phenolphthalein acidity.

Mine Sealing - As is the case of the Allegheny River, the curve on Figure Ac-12 can serve as a basis for estimating possible accomplishments by mine sealing. As a comprehensive mine sealing program is completed, it is assumed that the trend of acid discharge will leave the curve of cumulative coal production and drop to the line representing "estimated acid load trend with comprehensive sealing program at 70 per cent efficiency." There is evidence in the form of the curve that the trend of river water quality, as shown on Figure Ac-12, is already dropping to a line representing residual acid after sealing. However, this cannot be stated with positive assurance on the basis of water plant records for a number of years. Assuming tentatively that the acid trend curve will drop to a curve representing the residual acid load after sealing, it can be concluded that a comprehensive sealing program would return the Monongahela River above McKeesport to the condition it was in 1920. Consideration of the quantity of coal that has been mined out and the magnitude of the comprehensive mine sealing program indicates that this conclusion is reasonable.

The maximum monthly acidity of the Monongahela River, above McKeesport, of 33 p.p.m. can be reduced by mine sealing and flow regulation to an estimated 4 p.p.m. Of this 29 p.p.m. reduction of acidity, 19 p.p.m. can equitably be assigned to mine sealing. Improvement in average quality would be much less. A lesser improvement should also result in the Ohio River.

Flow Regulation - As in the case of the Allegheny River additional improvement is possible by the use of flow regulation from reservoir storage. It is estimated that the use of reservoir capacity totaling 370,000 acre-feet can accomplish a reduction in the maximum monthly acidity equitably estimated at 10 p.p.m.

Objectives and methods of operation are the same as described for the Allegheny River Basin except that flow is increased only up to the average flow of 10,950 second-feet.

Benefits and Costs

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela and upper Ohio River Basins due to the suggested mine sealing and flow regulation programs total $1,133,000 per year. That this estimate is conservative is indicated by the following considerations:

(1) The estimate is based on 1940 damages whereas Table Ac-3, page 9 , indicates that estimated damages may increase 50 percent in the next 20 years.

(2) The estimate is based on a program of mine sealing under 1940 restrictions. A more complete sealing program could reduce the residual acid load an estimated further 50 percent and should yield much greater benefits. Costs would be higher but not in proportion to the increased benefits.

(3) The estimate does not include benefits to: (a) decreased manganese in water supplies, (b) recreation, (c) agricultural uses, (d) highway structures, (e) the mines themselves or (f) indeterminate benefits to the public health. These damages might reasonably be considered to equal the estimated monetary damages.

The estimated cost of the restricted mine sealing program considered is $3,250,000. Annual charges of interest (3½%), amortization (0.7 or 3½% for 50 years), inspections (2%) and maintenance (7 to 10%) are about 15 percent or $488,000 on this additional expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000, making a total cost of $870,000 per year. As shown on Figure Ac-3, page 6 . if these existing seals are not maintained, the benefits already realized may easily be lost, making it necessary to repeat the expenditure.

If the remedial program is considered as a whole, this annual cost deducted from the total benefits would leave $263,000 for expenditures for flow regulation. While this allocation of benefits is not unreasonable, it probably does not do full justice to mine sealing which, if taken alone, will amply justify itself from a monetary benefit standpoint.

Additional benefits because of organic pollution abatement are also available to flow regulation.

Organic Pollution Abatement

Organic pollution in the upper Main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 c.f.s. during the warm summer months (25°C. or 77°F. average monthly air temperature) and lesser flows during the colder months. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drouth occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drouth. A valuable partial organic pollution control would be available even during a year such as 1930.

Without flow regulation a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is $300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional $300,000.

While the flow regulation is designed primarily for acid pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a

valuable aid in organic pollution control. The two flow regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic pollution control. An examination of flow and acidity records indicates that acid control and organic pollution abatement can both be accomplished with the exception of one month (also excepting 1930) in ten years and this accomplishment has been taken as satisfactory.

Storage required for organic pollution abatement is 430,000 acre-feet (except in 1930) while flow required for acid control is 210,000 acre-feet in the Allegheny River Basin and 370,000 acre-feet in the Monongahela River Basin or a total of 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Annual benefits to flow regulation include $263,000 left after deducting mine sealing costs from acid and hardness control benefits, plus $300,000 for organic pollution control at Pittsburgh and $300,000 for organic pollution control benefits at Cincinnati, making a total of $863,000 per year. As the storage required is 570,000 acre-feet, the annual benefits computed are about $1.49 per acre-foot.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-Upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

The essential features of the acid and organic pollution control program on the upper Ohio River Basin is shown in the "Summary for Main Report" which is also included in the first part of this supplement.

Personnel

The acid mine drainage studies, with the exception of laboratory activities, were carried out under the administrative direction of Senior Sanitary Engineer H. R. Crohurst, in charge of the Office of Stream Sanitation. The work was organized and carried out under the general direction of Sanitary Engineer (R) Ellis S. Tisdale and under the immediate supervision of Senior Public Health Engineer M. LeBosquet, Jr. A field office was established in the Office of Mine Sealing of the U. S. Public Health Service, Regional Consultant E. W. Lyon in charge. This field office for the Ohio River Pollution Survey was placed in charge of Assistant Sanitary Engineer (R) Paul D. Haney. Assistant Sanitary Engineer (R) Ralph C. Palange and Assistant Chemical Engineer Royal E. Rostenbach were assigned to assist in the work.

Laboratory activities were performed under the administrative direction of Senior Sanitary Engineer J. K. Hoskins, in charge of the Stream Pollution Investigations Station, succeeded in July, 1940, by Medical Director H. E. Hasseltine. Technical direction of the work was by Senior Sanitary Engineer H. W. Streeter. Passed Assistant Sanitary Engineer (R) C. L. Chapman was in charge of special acid stream work at Morgantown, W. Va.

Estimates of accomplishments and financial benefits of acid control measures were prepared in the Cincinnati office, and the final Supplement "C" is the joint work of Messrs. LeBosquet and Haney with assistance in the preparation of estimates by Mr. Palange.

The supplement was reviewed by Mr. Lyon, R. D. Leitch, Chemical Engineer of the Bureau of Mines, Pennsylvania officials and others. Valuable contributions were made in these reviews.

OHIO RIVER POLLUTION SURVEY

FINAL REPORT
TO THE
OHIO RIVER COMMITTEE

SUPPLEMENT "E"

EPIDEMIOLOGICAL STUDIES

U.S. PUBLIC HEALTH SERVICE
1798

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
CINCINNATI, OHIO
1942

EPIDEMIOLOGICAL STUDIES

By

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Supplement "E" to
Final Report to the Ohio River Committee
Ohio River Pollution Survey

FEDERAL SECURITY AGENCY

U. S. PUBLIC HEALTH SERVICE

STREAM POLLUTION INVESTIGATIONS STATION

CINCINNATI, OHIO

1942

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SUMMARY

Field studies of water-borne disease on the Ohio River watershed were made during the Ohio River Pollution Survey, 1939-1940. These studies covered field epidemiological investigation of outbreaks of apparently water-borne disease; field bacteriological studies of these outbreaks; laboratory experimental studies, not definitely connected with outbreaks of disease, and statistical study of mortality from diarrheal and enteric diseases throughout the watershed.

Two outbreaks of gastro-enteritis, a mild affliction characterized by nausea, vomiting, cramps and diarrhea, lasting but a few days and, practically with no mortality, were studied in detail.

One outbreak of bacillary dysentery (Shiga), an acute illness, extending over several weeks with considerable mortality, was studied during the closing days of the Survey. This outbreak of dysentery contrasts sharply with those of the mild, transitory gastro-enteritis.

Evidence was obtained that this type of gastro-enteritis is of infectious nature and water-borne. Experimental studies on human volunteers suggested the possibility that this form of gastro-enteritis may be due to some hitherto unrecognized causal organism which may not be detected by the usual bacteriological tests applied to determine the potability of water.

Statistical evidence obtained in 43 cities of the Ohio River watershed, indicate that filtration and chlorination of water supplies did not reduce the diarrhea and enteritis death rate to the same extent that these measures reduced the typhoid fever death rate, basing this finding on a comparison of death rates for the 5-year period preceding the establishment of filtration and/or chlorination with the 5-year period immediately following installation of these water purification procedures.

WATER-BORNE DISEASE STUDY

I. Aims

The virtual conquest of water-borne typhoid fever along the Ohio River has been effected by the installation of adequate water treatment facilities in the great majority of the cities and towns using surface water supplies. There remains, however, an epidemic disease (by no means limited to the Ohio River Valley) generally considered to be carried by water and usually referred to as "Gastro-enteritis, presumably water-borne". Individual cases of this ailment show symptoms of nausea, vomiting, cramps and diarrhea lasting usually one to three days. So similar are the symptoms to the common food-intoxications that patients are quite likely to attribute their trouble to something eaten at a recent meal, until they learn of numerous cases occurring simultaneously among friends and neighbors. Because food poisoning is a relatively common occurrence and the symptoms, though often severe, have been experienced before, a physician is not likely to be called and extensive epidemics with cases occurring actually in the families of physicians have escaped medical attention entirely or have been dismissed as unimportant. Individual cases are not always easily distinguished from summer diarrhea or mild dysentery. The vomiting, the lack of fever, the short course, the watery, often fetid, stool and the aversion to fluids despite often severe dehydration, are more typical of gastro-enteritis than of the above mentioned more ominous conditions.

Although individual cases are not always easily differentiated from the more common ailments noted above, the disease is easily identified by its behavior in groups of people--in other words by its epidemiology. When the specific cause of a malady is unknown, it not infrequently happens that it can be more readily identified by its mass behavior than by the symptoms produced in individual cases. Thus influenza was formerly differentiated from grippe and other seasonal disturbances by its high attack rate and rapid spread from person to person. Water-borne gastro-enteritis--often erroneously diagnosed "intestinal influenza"--shows these same attributes in even more striking degree. As much as 60 percent of the population of a town has been known to be attacked

within a period of two or three days to a week--a far more explosive condition even than influenza, which usually requires a full week, even in a small community, to reach its maximum prevalence and is not wholly over in two or three weeks. Like influenza, this form of gastro-enteritis is frequently a cold weather disorder and all ages are indiscriminately attacked. These characteristics assist in differentiating the condition from the food poisonings and summer complaints which tend to prevail in summer and early fall and attack the younger age-groups more than the older. Quite striking, also, is the low mortality from water-borne gastro-enteritis when this is not accompanied by another more lethal water-borne condition such as typhoid fever. Less than one person dies per thousand persons attacked and the occasional death usually occurs in individuals stricken with some co-existing acute or chronic disease--almost never in a previously healthy person.

As was noted above, the cause of true water-borne gastro-enteritis is obscure. Occasionally outbreaks have been explained on a chemical or specific bacteriological basis. Because the human gastro-intestinal tract has only a limited number of responses to a wide variety of harmful materials, it is not impossible that each outbreak may have a separate cause. It is known that the drinking of water contaminated with relatively small amounts of sewage can result in acute gastro-enteritis. Outbreaks of gastro-enteritis from this cause occurred more frequently two or three decades ago than they do at present, and were often followed by infections with the typhoid organism, then fairly common in sewage.

Sewage regularly contains great numbers of coliform bacteria, in and of themselves harmless, but valuable as indices of sewage contamination in drinking water. Tests for the detection of coliform bacteria are therefore made as a routine procedure in most water treatment plants.

Occasional outbreaks of gastro-enteritis have been traced, however, to water in which sewage pollution was not found by the coliform tests applied. The impression has crystallized among leaders in the water treatment field that causes other than sewage pollution may occasionally produce gastro-enteritis, and it was thought advisable to make a determined effort to learn the cause or causes

of these outbreaks, so that, if really needed, further tests could be devised to insure the safety of drinking water.

Moreover, there was another cause for official concern. Physicians in attendance upon cases of summer complaint and the various diarrheal diseases of the warm months, puzzled by the almost epidemic prevalence of these conditions at times, not infrequently blamed the water supply either for inadequate treatment or for excess of chemicals.

The problem appeared therefore to be a two-fold one--first, to determine the causes and prophylaxis of water-borne gastro-enteritis of hitherto undetermined etiology, and second, to learn enough, if possible, of the causes and mode of infection of summer complaints to determine their relationship to water as a possible vehicle of the ailment.

II. Personnel and Equipment

To fulfil this dual purpose the epidemiological unit was organized and equipped for a somewhat diversified attack on the problem by the late Surgeon Filip C. Forsbeck. His untimely death in July, 1940, was a serious set-back for the study; arrangements were, however, made to complete the study very nearly in accordance with his original plans. The personnel consisted of an epidemiologist in charge of the unit, who was to carry out field studies on outbreaks and to supervise the work of other members of the unit, and a bacteriologist to examine water, stool, and other specimens secured in the course of the field work. For the preparation of media and glassware a laboratory assistant was assigned to the bacteriologist. Finally there was a statistician for the larger cities of the Ohio River Valley, to assist in the analysis of epidemic data and to help in epidemiological studies in the field during the course of outbreaks.

The headquarters of the unit, which was a subdivision of the Ohio River Pollution Survey, were at the U. S. Public Health Service's Stream Pollution Investigations Station in Cincinnati where extensive laboratory facilities and able advisory assistance were made available. Because it was recognized that water and stool specimens were best

examined immediately, a trailer laboratory completely equipped for bacteriological study of pertinent specimens and samples was developed for work at the site of an outbreak.

Good relations with the Health Departments of the several states forming the Ohio River watershed were established early in the study and renewed by periodic collaboration on various projects. Outbreaks of waterborne gastro-enteritis are not common and, because of their ephemeral character, it was necessary to keep in close touch with State health workers--particularly with the sanitary engineering groups, in order to learn of outbreaks during their early phases.

III. Methods of Field Study

When notification of a city or town outbreak was received from a State health department, the local health department having jurisdiction was contacted and permission obtained for participating in the study.

The epidemiologist and statistical assistant usually preceded the laboratory, selected a central location for the trailer and arranged for the electric and other connections which it required.

Definite establishment of the fact that an epidemic was occurring was an early and vital feature of their work. This entailed (1) a study of school absences--which invariably show a sharp increase when an outbreak of any magnitude has begun--and (2) visits to local druggists to inquire whether sales of castor oil, bismuth preparations and paregoric had shown a sudden sharp increase. When these inquires to druggists are properly addressed, surprisingly uniform and frank responses are nearly always obtained. Druggists know the volume of their usual seasonal sales of these preparations and can give surprisingly good statements of the comparative sales during any period of inquiry. The files of recent local newspapers also give good data on the time at which the outbreak, if any, first came to public notice and on the antecedent local weather conditions. If, from these various preliminary inquiries, there was good basis for believing that an outbreak was in progress, a map of the

local water distribution system was secured and a number of water samples was obtained from selected sampling points on the main grid of pipes, on all dead ends, and from the source of supply both before and after treatment, if any treatment was used. Besides subjecting these samples to bacteriological study, an important test made on these early samples (where chlorine was routinely used) was a test for residual chlorine.

Next, a house-to-house canvass was conducted of a random sample of the population, using the form shown in appendix (I). This form was developed with a view to obtaining the most important information within a minimum of time. It can be filled in completely in less than 10 minutes in the average household, and two canvassers working for half a day can secure a very respectable population sample. Preliminary studies of this half-day's work usually give a fairly definite idea of whether water is the vehicle of the infection. In canvassing, an attempt was made first to secure a random sample of households straight across the town or city in one direction and then in another direction perpendicular to it. In this way geographic distribution of cases can be added to the information obtained from the age, sex, and other data of importance. In most localities a certain number of persons can be found who do not habitually use the city, or town, water supply for drinking purposes but resort, instead, to well, cistern or bottled spring water. As large a sample of these individuals as possible was obtained early in order to determine the extent to which they were attacked. It is also important, where infants are living in a household, to determine whether their water and milk were boiled or given raw.

An intensive bacteriological study of the water supply was carried on coincidently with the epidemiological survey. In selecting sampling points, a careful inspection was made of the pumping station, treatment plant and distribution system. On the distribution system points for sampling were selected so that freshly treated water would be tested as well as water from dead ends. To obtain more complete information concerning the bacterial content of the samples, two procedures were followed, (1) the sample was examined for coliform bacteria in accordance

with Standard Methods to determine whether the water met the requirements of the Treasury Department Standard, and (2) lactose broth tubes showing growth, but no gas, were examined to determine the type of bacteria present. In making determinations on portions of water, much larger in volume than prescribed by Standard Methods, a concentration procedure was developed.

The samples were examined as soon as received. Portions of 10 ml. each were measured into 10 tubes of lactose broth, incubated at 37° C. for 24 hours and examined. A second reading was also made after 48 hours. Those tubes which showed gas were transferred to brilliant green bile broth and streaked to MacConkey's agar plates at each examination period. A positive result in either medium was considered sufficient confirmation for the presence of members of the coliform group.

The tubes which showed no gas but did show the presence of growth were streaked on MacConkey's or other selective media plates, as the nature of the work might indicate, and the plates incubated 18 to 24 hours at 37° C. To obtain information regarding the flora, other than coliforms, present in the water, at least two representative non-lactose fermenting type colonies would be fished from each MacConkey plate to Russell slants. Russell's medium was used because it was considered worthwhile to learn something about the presence of proteus and the atypical slow lactose fermenting types which might be present. If the Russell tubes gave evidence of a consistent flora for the sample, one of the duplicate cultures was discarded at this point and the remaining cultures purified by streaking on MacConkey's agar, after short-time incubation in broth. Two well-isolated colonies were picked from the plate and again inoculated in Russell tubes. Where more than one type of colony appeared, two of each were fished. If these Russell tubes gave similar reactions, one culture only was retained for further study.

For the study of unfinished or raw waters the above procedure was modified as follows: If not highly polluted, five 10 ml. portions were planted into lactose broth directly and three portions in each of several serial dilutions added as indicated. It was always considered essential to have at least one tube in the highest dilution which showed no growth. In all cases primary consideration was given to flora found in tubes with no gas formation or in the dilutions higher than that required to give the

coliform index.

Because of the small number of bacteria to be found in treated water, a method of concentration was worked out and given practical test on water samples collected from Cincinnati and the surrounding communities within a radius of 75 miles. By this technique any desired portion of the water sample is filtered, with the use of suction, through an apparatus sold commercially under the name of Jenkins filter. By experimenting it was found that if the original filter blocks supplied with the apparatus were cut to a thickness of approximately 3 to 5 mm., the filtration time for a 100 ml. portion would be about 30 minutes.

Control tests were run on water samples known to be contaminated and on known suspensions of coliforms in distilled water. If the filter disc did not retain greater than 95 percent of the organisms it was discarded. With but few exceptions the filtrates were sterile. If there were many bacteria or an increased amount of inorganic material in the sample, difficulties were met in filtering. In the experimental work two portions of 100 ml. each were filtered. The rubber sleeve holding the filter disc containing the bacteria was removed from the apparatus and with sterile rod the disc was pushed into a tube of enriched medium. Lactose broth and selenite F were used for enrichment. Incubation was at 37° C. and after growth appeared, the material was streaked on MacConkey or other selective media plates, the colonies fished and purified, with the technique outlined above. A comparison of the results of the concentration technique against the results from the ten 10 ml. portions planted in the standard manner showed a close agreement in the number of coliforms found. Moreover the same strains of bacteria were isolated by the concentration method as were obtained with the standard procedure.

After the cultures obtained by the above described methods had been purified, they were examined for gram reaction. Impure cultures were replated. Cultural, physiological, and fermentation characters were obtained and a tentative identification made. It was found that with these methods it was frequently possible to obtain organisms belonging to the genera Salmonella, Eberthella, Shigella, Pseudomonas, Proteus and Alcaligenes as well as atypical coliforms. It is not clear what relationship these forms bear to the pollution of the water. After a

careful study of many strains which appeared to be Salmonella, Eberthella or Shigella the results indicated that they were in reality atypical forms of Proteus. There were many forms which we were unable to identify by our present system of classification. Dr. P. R. Edwards of the Department of Animal Pathology, Agriculture Experiment Station, University of Kentucky kindly assisted with the identification of the suspected Salmonella strains. In one instance a culture of S. aertrycke was isolated from a dead end sample taken from a Cincinnati water tap. On several occasions S. oranienburg was isolated from raw water of Royal Spring, the source of supply for Georgetown, Kentucky.

Cultures which gave a neutral reaction on Russell's double sugar or Krumwiede's triple sugar tubes were at first discarded as being Alcaligenes and unimportant. Later work indicated that these cultures were frequently a variety of Pseudomonas. It was found that very often cultures of Pseudomonas were present which failed to give the fluorescing character used for identification. Special methods were devised for identifying these strains but this work as yet is incomplete. All cultures which gave neutral or alkaline reactions on Russell's or Krumwiede's were sub-cultured on synthetic dextrose agar slants. Pseudomonas on this medium gives an acid slope with a neutral butt. Most cultures produce a fluorescence when grown in synthetic asparagin broth containing mannitol. Thus far all of these strains have been citrate positive and indole negative.

In epidemics of this type it is of major interest to find out whether any of the organisms present in the water supply appeared as the predominant organism or in any considerable number in the stools of gastro-enteritis cases which had used the supply. Where possible stool specimens were obtained and examined microscopically and smeared on plates of selective media such as MacConkey's agar, desoxycholate citrate agar, Bacto-Shigella-Salmonella agar and bismuth sulfite agar. Suitable portions of the stool were placed in selenite F for enrichment and the growth streaked on the selective media. Suspicious colonies were fished to Krumwiede's triple sugar tubes and those showing a neutral reaction throughout, or a neutral slant and acid butt, with or without gas, were further identified by cultural, physiological and serological characters.

Small outbreaks involving a limited number of persons, or families, drinking water from a polluted well or cistern, or involving some institution on a private supply are probably not uncommon. These would not ordinarily come to the attention of the state health departments.

IV. Findings in Water-borne Gastro-Enteritis Outbreaks

Three outbreaks were brought to the attention of the Epidemiologic Study Unit during the period of active field investigation.

1) The first occurred in an Indiana town of nearly 9,000 persons early in February, 1940. The Unit was first informed of the outbreak several months afterward but detailed studies, made by the Bureau of Sanitary Engineering of the Indiana State Board of Health and summarized in a Bureau Report of April 29, 1940, were kindly submitted to the unit. A house-to-house canvass of 1,431 persons in the town, soon after the epidemic, showed that 302, or 21 percent, had suffered with nausea, vomiting or diarrhea between February 1st. and February 5th. The figure 1,431 includes 271 persons obtaining their drinking water from wells, cisterns and other independent sources. As none of these latter persons reported an attack, the incidence rate for the remainder, using town water, was nearly 26 percent. This locality obtains water from a river, at a point, thirty miles downstream from a town of 10,000 inhabitants. A prolonged cold spell had converted the river at low stage into an ice-covered conduit. Toward the end of January several million gallons of strawboard-waste had broken through an embankment into the river above both towns, suddenly and tremendously increasing the chlorine demand and contributing undesirable tastes and odors. Chlorine dosage was not increased sufficiently to cover the chlorine demand of the water in the town experiencing the outbreak, and repairs to filters were in progress, permitting turbid water to get into the mains on more than one occasion. A probable explanation, then, was that nearly untreated sewage-polluted water was used for drinking.

Other towns using surface water still further downstream suffered progressively milder outbreaks at successively later dates, but towns supplied from wells escaped.

This series of outbreaks suggests a small-scale repetition of the series of outbreaks occurring on the Ohio River in the winter of 1930-31 and described by Veldee (1).

2) On November 18, 1940, the Division of Sanitary Engineering of the Kentucky State Health Department invited the collaboration of the water-borne disease unit in the study of an outbreak characterized by nausea, vomiting, cramps and diarrhea in the city of Georgetown, Kentucky. A detailed report of this outbreak is contained in appendix(II). This epidemic was studied early, under very nearly ideal conditions of observation, and revealed an epidemiological pattern with which other outbreaks observed in the study and culled from the literature have conformed.
First, the onset of the epidemic was explosive and the duration short.
Second, the incidence among persons using private well and cistern water for drinking was much lower than that among persons using the city supply.
Third, the age and sex distribution of cases in a canvassed population was nearly uniform, indicating that there is no increment of immunity in a population with age or occupation.
Fourth, there was a definite incubation period of 36-72 hours, suggesting an infectious, as distinct from a toxic, etiology.
Fifth, explosive gas formation in standard lactose broth was noted in the 48 hour reading of numerous water samples taken early in the course of the outbreak but this, with the exception of one sample, failed to confirm for coliforms.
Sixth, stools of patients, extensively studied with reliable media, failed to show a common etiological agent.

In detailed studies of all but one of the early water samples and from a limited number of stool specimens, organisms identified as a species of Pseudomonas were isolated and hopes were entertained of this being shown as a causal factor. However, more extensive experimental study of three human volunteers with this and other strains did not confirm these hopes. The finding, however, warrants mention as no other organism was found common to both stool specimens and water samples from this outbreak.

The source of supply, the Royal Spring, was found to be subject to more or less extensive pollution--particularly after rains. Treatment (coagulation, filtration and chlorination) was found to be inadequate. The settling basins were heavily lined with blue-green algal masses (oscillatoria) and dead masses floated on the surface, adding to the organic load and possibly contributing both a tint and a taste to the treated water.

No explanation was found, however, for the comparative freedom from pollution, as evidenced by standard tests of the treated water for coliform bacteria at the time the early samples were taken.

3) Early in March, 1941, the water-borne disease study unit was invited by the Ohio State Health Department to participate in a study of an outbreak closely resembling the Georgetown epidemic, in the village of Navarre, Ohio. A detailed report of this outbreak is contained in appendix(III). As this occurrence was nearly over before it came to official notice, no stool specimens were secured. Early tests of the village water by the State Health Department laboratories revealed the presence of coliforms in 10 ml. and even 1 ml. portions. In other respects, however, the outbreak was nearly an exact replica of the Georgetown occurrence noted above.

No evidence of contact transmission could be obtained in house-to-house canvass. Where some in a given home had used the suspected supply and others had not, the infection was always limited to the former. Prolonged pumping of the wells from which the water supply was derived, showed very limited numbers of organisms appearing only at the end of the pump run. These organisms were identified as a species of Pseudomonas. Coliforms at no time appeared in the samples from the pump, though in samples from some points on the distribution system slow-lactose fermenting organisms and Pseudomonas were found. No evidence of pollution at the source, and no point at which pollution entered the distribution system was definitely discovered in Navarre.

The three outbreaks outlined above were the only ones brought to the attention of the unit. The last two were studied under exceptionally favorable conditions and with considerable care. No definite etiological

agent was found. However, certain features were ascertained. The outbreaks at both Georgetown and Navarre were quite conclusively proven to be water-borne. An incubation period for water-borne gastro-enteritis was established, suggesting an infectious etiology. Finally, a study of stool specimens in one typical outbreak failed to show an etiological agent.

V. Literature on Water-borne Gastro-enteritis

A study of previous experience with, and of the literature on, water-borne gastro-enteritis was undertaken with a view to amplifying these rather limited conclusions.

A detailed study of this entity by Cox (2) presents a list of hypotheses on the etiology, then a general consideration of a number of outbreaks, as well as a detailed study of a few, and concludes that pathogenic bacteria are usually involved. With his concept that the disease "is in the nature of a mild dysentery" some exception must be taken for reasons which will appear below.

The ensuing paragraphs will summarize briefly a number of references to outbreaks, a few of which were covered by the article of Cox mentioned above. Some of these were gleaned from the valuable publication of Wolman and Gorman (3) and others from various reference sources, as well as from correspondence with persons familiar with the circumstances. Certain details of these outbreaks not mentioned in the text are given in the table in the Appendix (V) when details were available. These include date and day of week of the first cases; duration of outbreaks; date of collection of water samples and interval in days between first cases and first samples; presence or absence of coliforms in first samples; source of water supply, number of persons using the supply, number and percent attacked and, finally, general remarks on each outbreak. The three outbreaks described in the previous section of this report have also been included in the appendix summary table and will be discussed together with those gathered from the literature.

Although the outbreaks to be described briefly below

all bear a strong mutual resemblance in their epidemiological features, they are differentiated into three groups on the basis of certain findings. The first group consists of epidemics of gastro-enteritis, apparently water-borne, in which no conclusive evidence of sewage pollution in the treated water was found by bacteriological analysis, and in which sanitary studies failed to disclose sufficient evidence of pollution of the supply by sewage. The second consists of epidemics with evidence of sewage pollution but without ensuing cases of typhoid fever. The third group consists of epidemics identical with the second except that typhoid fever followed the initial gastro-enteritis outbreak.

Group I. Of the three outbreaks described in the previous section, only that of Georgetown belongs in the first category, and this is possible only because the bulk of evidence indicated surface drainage, rather than sewage, as the most probable means of contamination of the water supply. A search of available sources reveals three others occurring in localities whose water, at the time of testing, met bacteriological standards of potability. These will now be described briefly.

Through the courtesy of the Massachusetts State Department of Health, the records of an outbreak of water-borne gastro-enteritis were made available to the unit. This epidemic occurred in Cohasset, Massachusetts, in March, 1931, and was studied by one of the authors, then epidemiologist in the Massachusetts State Department. Except for the fact that vomiting played a rather more prominent role than cramps or diarrhea, it followed very closely the epidemiological pattern described for Georgetown, of explosive onset, brief duration, uniform age incidence, high attack rate among users of town water only, bacteriologically normal water samples and absence of known pathogens in the stools.

In February, 1936, there occurred at Coshocton, Ohio, (4) an outbreak similar to those in Georgetown and in Cohasset, no contamination of the system being indicated bacteriologically despite a very definite distribution of cases on the local supply.

The localities so far mentioned have been small cities, towns or villages, all of which used ground water.

One large city, Milwaukee, suffered an outbreak, or a series of outbreaks, which resembled in many respects those outlined above. The most noteworthy one occurred in February, 1938 (5). Neither at this time nor in a previous outbreak, in 1936, were confirmed coliforms found in appreciable numbers, though there were elevated total counts and numbers of gas-formers, together with other evidence that water could not be exonerated.

Outbreaks in Georgetown, Cohasset, Coshocton and Milwaukee occurred with slight, if any, evidence of sewage pollution of the treated water. They had other elements in common, for they occurred in the late fall, winter or early spring, when the weather was cold. Of the four, only Milwaukee used a surface supply, although the Georgetown supply might be considered of surface origin in that the Royal Spring is apparently fed by surface streams which are subterranean for at least a part of their course. Three of these occurrences show an interesting aggregation of cases during or just after week-ends. This fact will be merely noted here and is to be discussed more fully below.

Group II. Two outbreaks--Navarre and the Indiana town reported above--have already been presented as probably due to sewage contamination but without subsequent cases of typhoid fever.

The literature offers a limited number of examples of known, or putative, sewage pollution outbreaks not followed by typhoid fever. In the group to be discussed the evidence rests upon the finding of coliforms in all, or at least in a fair proportion of, samples if not upon the actual demonstration of a relationship between the water supply and sewer system.

Another instance was that of the "Tennessee Town" (6) with periodic outbreaks in June, July and August of 1936. Evidence that sewage contamination of the raw water occurred is presented, though the treated water was felt to have been relatively safe.

In Dallas, (7) Texas, a single water main serving about 10,000 persons became polluted and occasioned a severe outbreak of gastro-enteritis in April, 1937.

In Altamount (8) New York, there occurred a village-wide epidemic of a similar nature in May, 1937.

In Vinton, (9) Iowa, in February, 1938, there was an outbreak of typical gastro-enteritis.

Noteworthy is the fact that only three of the six outbreaks in this group occurred in the winter.

In many of the outbreaks discussed in both groups up to this point reference is made to dysentery-like symptomatology along with the gastro-enteritis, but only in Cohasset, Georgetown, Altamount, and Dallas was there a record of a definite study of stool specimens and in none of these were possible pathogens found. Typhoid fever, noted above as developing not infrequently after this type of outbreak, was not observed in the wake of any of these epidemics.

Group III. There are several instances in which typhoid fever did develop after gastro-enteritis outbreaks traceable to contamination of drinking water. One of the classic examples is that of the "Excursion Boat Epidemic", reported by Lumsden, (10) in July, 1912. The succinct account of the gastro-enteritis phases of this outbreak is well worth reproducing verbatim:

"From Clinton (including Lyons) about 1,200 persons went on the excursion. Of these persons the writer estimates, from the data collected by Dr. Sugg and himself, at least 600 (or 50 per cent) became ill between 12 and 72 hours after their return from the trip. The illness was manifested usually by nausea and vomiting, diarrhea, and prostration. Diarrhea was the most constant symptom. The majority of the cases had nausea and vomiting along with the diarrhea. A few had nausea and vomiting without diarrhea. A small proportion had fever during the diarrheal attack. Some had rather severe abdominal pain. In the majority of cases the duration of the gastro-intestinal disturbance was from 3 to 5 days. In some cases the attack continued for only about 24 hours and in others for several weeks. In some of the cases there were recurrences at intervals of 3 or 4 days. The symptoms presented in the attacks were similar to those which have been presented in a number of outbreaks of diarrhea (sometimes referred to as outbreaks of "winter cholera") resulting from the use of water supplies polluted with sewage. Striking examples were furnished by the outbreak in Mankato, Minnesota, in 1908, (11) and the one in Rockford, Illinois, in 1912 (12).

"Among the residents of Clinton who did not go on the excursion trip on the steamer G. W. Hill on July 29 there was during the summer of 1912 no unusual occurrence of diarrheal disease -------------.

"The writer canvassed in Clinton about 50 households, some of whose members went on the excursion. The outbreak was sharply confined to those who went on the excursion. In a number of instances every member of a family who made the trip was attacked and every member of the family who did not go on the excursion was exempt."

This outbreak was considered to have resulted from pumping river water into the steamer's drinking water tank while the vessel was docked over a sewer outlet. Eleven cases of typhoid fever followed the gastro-enteritis.

In January, 1924, the city of Santa Ana, (13) California, suffered a severe outbreak of gastro-enteritis followed by an epidemic of at least 226 cases of typhoid fever. Cases of paratyphoid, dysentery and paradysentery were also diagnosed.

Detroit, (14) in February, 1926, had a similarly widespread outbreak which was, however, followed by the comparatively small number of eight cases of typhoid fever.

In the summer of 1926 an extensive outbreak of gastro-enteritis, followed by dysentery, paratyphoid and typhoid fever occurred in the urban district of greater Rostov On-the-Don (15) in Russia. There were 2978 cases of recognized typhoid and paratyphoid fever in this outbreak.

The Chicago stock-yard fire on May 19, 1934, gave rise to a most interesting outbreak, reported by Hardy & Spector (16). While fighting the fire a number of firemen drank polluted water and experienced mild attacks beginning one to three days later, characterized by nausea, occasional vomiting and diarrhea. A larger number were reported to have had more intense symptoms lasting for several weeks. Evidence is presented incriminating <u>Endamoeba histolytica</u> in this latter type of case. Sixty-nine cases of typhoid fever and two cases of paratyphoid fever were also reported. A useful description of the gastro-enteric features of the outbreak

is included in this report and a new symptom added to the syndrome--progressive loss of weight. This symptom will be mentioned again below.

An outbreak, carefully studied from the laboratory point of view by Ziegler, (17) occurred at Springfield, Missouri, early in July, 1936. Cases were described as having less uniform symptomatology than in the epidemics just outlined. Organisms not fermenting lactose, or fermenting it slowly, were isolated from water samples and from some of the stool specimens.

In December, 1940, an old cross connection was briefly opened in Rochester, (18) N. Y., allowing polluted water from a high-pressure fire control system to flow into the regular water supply mains. The cross connection was open from about 4:30 P.M., December 11th, to 8 A.M. December 12th. More than half the gastro-enteritis cases canvassed had onsets on December 13th and 14th and six cases of typhoid fever followed in due course.

It is notable that in this last group of outbreaks, featuring typhoid fever cases, reports of other enteric syndromes such as dysentery and paratyphoid fever are more prominent. In the first two groups discussed--those with no evidence of sewage pollution and those with evidence thereof, but not followed by typhoid fever--much milder syndromes with no mortality and with a greater predominance of gastric symptoms (nausea and vomiting) are detailed.

As noted above more data are available on these outbreaks in appendix V. Information on dates of the beginning of epidemics has been included there because there seems to be a tendency for outbreaks to start on, or very shortly after, a weekend or holiday. This was the case in Georgetown, Navarre, Cohasset, Coshocton, Dallas, Altamount, Milwaukee and in the "Tennessee town" (where weekend outbreaks were noted periodically during the summer). In Milwaukee daily case totals increased markedly on Mondays for three successive weeks. Two outbreaks starting in midweek--those in the "Indiana town" and in Rochester--followed repair work on the respective systems. The implication of this weekend and holiday grouping is obvious when it is remembered that even in large cities the operating staff of water works is generally reduced at such times and vigilance consequently relaxed.

One outbreak, epidemiologically resembling the milder form described above, has not been included with them because it was attributed to another cause. On May 6, 1939, an epidemic of nausea and vomiting, with or without diarrhea, occurred in one section of Olympia, Washington (19). Although back-siphonage was found to have occurred at the local school, no bacteriological evidence of pollution was found and the outbreak was attributed to volatile poisons from the painting of a water tank restored to service on May 4. School children were affected primarily and the onsets of cases were noted as occurring in the early morning hours--a rather delayed onset for most chemical intoxications. No mention is made of tastes or odors in the water likely to be associated with volatile chemical poisons.

The European literature has been but lightly considered in the above discussion. Papers by Hornung (20) and by Rimpau (21) describe outbreaks. Kathe and Konigshaus (22) and Knorr (23) also deal with the subject. The study of the Hanover Typhoid Outbreak by Mohrman (24) contains some data on gastro-enteritis.

A review of the literature should not be ended without mentioning the stimulating contribution by Schaut (25). This author cites a body of evidence to show that organic cyanides of vegetable origin may be present in water and urges that these be considered as a possible cause for gastro-intestinal outbreaks originating from water. Further observations on this will be made below.

The conclusion derived from field work and from a review of the literature on the subject is that water-borne gastro-enteritis is a definite infectious entity quite distinct from the dysenteries, paratyphoid and typhoid fevers. Because it has an incubation period it appears to be a virus or bacterial infection rather than the result of a chemical intoxication. It should be noted, however, that there is theoretically a hybrid between the infectious and toxic hypotheses which cannot be ruled out on the basis of this reasoning: quite possibly the ingestion of water containing an organism capable of rapidly producing hydrogen sulphide, cyanide, or one of several amines, or other decomposition products in the intestinal tract, could produce a syndrome of this sort.

The disease is not readily communicable from person-to-person by contact. The varied symptomatology suggests a complex of infections rather than a single type, but this variation in symptoms may be the result of variations in dosage, or of idiosyncrasy. The etiological agent, or agents, have not been identified. The findings in Springfield, Missouri, are suggestive but have not been confirmed in other outbreaks.

That the disease is spread by water and often by sewage pollution of water is definitely established. However, there is room for some doubt as to whether sewage contamination is the sole source of the infection, in view of the occasional instances in which no such pollution could be demonstrated. The experience in the field and a review of the literature leave but two deductions on this point: either (a) sewage pollution is a common but not an only source, or (b) the bacteriological standard, with its heavy emphasis on coliform detection, is not an infallible index of water conditions affecting the prevalence of gastro-enteritis. Both points of view will be found expressed in the literature and both may, of course, be correct.

As some of the laboratory studies conducted by the unit bear upon these questions, they will be discussed after these studies have been presented in the next section.

VI. Experimental Laboratory Findings

Because outbreaks were few in number and because several leads were obtained in the course of field work, laboratory studies were carried out. Among the most pertinent of these were observations upon the effect of Berkefeld-filtered sewage taken orally by human volunteers.

1. Experiments with Berkefeld-filtered Sewage.

Fresh human sewage from a sewer pipe draining a populous hillside in Cincinnati was used for these experiments.

The first experiment was carried out with a single volunteer who drank 250 ml. of sewage filtered through a Berkefeld N filter. The filtrate was clear, contained

fewer than two coliforms per 100 ml. (no gas formation at 48 hours at 37° C. in five 10 ml. portions planted in lactose broth and the number of bacteria growing on plates after 48 hours incubation was about 5 per ml.); gram-stain of the sediments in the lactose broth tubes revealed only gram-negative elements--chiefly Pseudomonas and vibrioid organisms. However, a small spirochaete was also detected by dark-field examination and found to be the most abundant organism in the filtrate.

Thirty-two hours after taking this filtrate the volunteer developed a profuse watery diarrhea lasting 18 hours, and a few hours after this began he became nauseated and retched without actually vomiting. Temperature was normal or subnormal at the start and rose to 101° F. after a considerable period of diarrhea with dehydration. Extensive examination of four stool specimens upon a wide variety of media revealed no significant organism. A rather surprising finding after recovery was a progressive loss of weight from 180 lbs. to 170 lbs. in the ensuing ten days.

Re-examination of the sewage filtrate after being stored in the ice box at 40° F. for 48 hours revealed a 20-fold increase in the bacterial count which was largely due to proliferation of Pseudomonas. Some strains of this genus are known to be cryophilic.

Three months later another lot of sewage was filtered through two Berkefeld N filters and ingested by four volunteers--one of them the original recipient of the material described above. Filtration was less efficient this time, filtrates from both filters showing an M.P.N. of 13 coliforms per 100 ml. and a count of 160 bacteria per ml. at 48 hours. Color-producing Pseudomonas were detected in one filtrate but none were isolated from the other, though organisms with similar cultural characters without color-production were obtained from the latter. Vibrioid organisms were not found but spirochaetes were abundant in both samples. As in the previous experiment, the only other organisms found in these filtrates were gram-negative.

Two volunteers drank 250 ml. and 50 ml. respectively of one filtrate and two received similar amounts of the

second. The original volunteer experienced an attack identical with the one he experienced in the first test, even to the length of the incubation period. His weight loss subsequently was, however, more marked (15 lbs.). Another volunteer was nauseated and vomited twice after a 34 hour incubation period. The other two experienced nausea and diarrhea, with malaise, abdominal cramps and constant, dull abdominal pain for 12-18 hours. One of these last also showed a progressive weight loss during the period following convalescence. Spirochaetes, very similar in appearance to those found in the lactose broth cultures of filtrates, were observed in one freshly-passed stool. No known pathogens were detected upon extensive study of stool specimens from these patients.

A final experiment was performed with six volunteers drinking from 50 ml. to 250 ml. of sewage filtered first through a Berkefeld N and then through a Berkefeld W filter. The filtrate produced no visible growth in lactose broth tubes at 48 hours and was considered virtually sterile. It remained in the icebox during this period and was taken by the volunteers only after this fact had been ascertained. Five volunteers showed no effects, but the sixth, who had received only 50 ml., developed marked nausea and a mild diarrhea without fever after an incubation period of 48 hours. Samples of the filtrate used in this experiment planted in lactose broth developed a faint haziness on the third day, and by the sixth it was evident that all of the six 10 ml. and three out of six 1 ml. portions contained either vibrioid organisms, or spirochaetes, or both. _Pseudomonas_ was not found in this filtrate.

The information furnished by these data on the causative agent of the disease is fragmentary and inconclusive. The spirochaete was the only organism consistently found in all the filtrates, and the possibility that it was responsible was, perhaps, the best lead obtained. Such an organism would not be expected to develop on the agar media ordinarily used for isolation of intestinal pathogens, thus accounting for the failure to find causative agents in stools. The incubation periods observed are, however, very short for a spirochaetal disease.

In this connection it should be noted that Kathe, (26)

and Prausnitz & Lubinski, (27) have described an entity, designated "Schlamm fieber," with an incubation period of very short duration to which a spirochaetal etiology is ascribed. Wolter (28) endeavored to attach this diagnosis to the gastro-enteritis preceding the Hanover outbreak.

While these experiments failed to reveal the responsible agent they are of considerable importance for they reproduced in the laboratory, under somewhat controlled conditions, attacks very similar to those witnessed in the field--and the filtrates, it will be noted, showed variations quite comparable to those encountered in the field so far as coliform tests were concerned. They support the field experience that sewage contains an agent giving rise to gastro-enteritis which is not ordinarily isolated on the media commonly used for the study of enteric disease. Unless the 48 hour period of retention of the material of the last experiment in the ice-box destroyed infectious or chemical elements, these experiments also disprove the virus as well as the chemical theory of etiology. Finally, they indicate that the agent responsible for at least one form of gastro-enteritis may be considerably more filterable than the coliforms used as an index of sewage pollution.

More intensive studies of sewage filtrates and of their experimental effects are clearly desirable.

2. Experiments with Pseudomonas. Certain experimental studies were also made upon strains of *Pseudomonas* encountered in the field and laboratory studies above described. Methods of quick isolation and identification of *Pseudomonas* strains were evolved. These organisms grow readily on most of the media used for stool examination and water analysis. Streaked on nutrient agar, the green or blue color production was found to be inconstant after incubation at 37° C. but to be quite dependable when incubated at 20°, or when 37° cultures were left for a few hours in the ice box. Upon opening closed petri-dish plates containing cultures of several strains, a distinct odor of cyanide was often observed, and amounts of cyanide up to 0.6 parts per million were removed from broth cultures growing under partially anaerobic conditions by the methods outlined by Patty (29).

It is not impossible that at least some of the cyanide noted by Schaut (25) in waters may be derived in part from this ubiquitous organism.

LaCorte (30) has stated that filtrates of gelatin cultures of Ps. pyocyanea produced death with bloody diarrhea when injected introduodenally into animals.

In the laboratory studies which follow, filtrates of lactose broth and of gelatin cultures of Pseudomonas strains were taken orally on an empty stomach by three human volunteers. Subsequently whole cultures containing several millions of organisms were also taken in the same way by two of these volunteers. No nausea, vomiting, diarrhea, or cramps were noted in these experiments with whole cultures.

When filtrates of cultures are taken in amounts from 5 to 20 ml. in 50-100 ml. of water, a definite local anaesthesia of the tongue, fauces, and pharynx is noted which persists for several hours. There is a transient feeling of epigastric soreness. For one or two days after the ingestion stool specimens, streaked on MacConkeys agar; may show little or no growth (even when heavy innocula are used).

When whole cultures of Pseudomonas are ingested the organism may or may not appear in the subsequent stools. These frequently showed, however, the same relative lack of growth on MacConkey's agar that was noted in experiments with filtrates. When Pseudomonas was recovered from the stool it was quite likely to be in pure culture at first, gradually being replaced by coliform colonies in subsequent stools. The incompatibility between Pseudomonas and coliforms in common culture is not limited to the human intestine. Pseudomonas cultures are known to exert a bacteriostatic, if not actually a lethal, effect, upon many other bacteria in vitro. West (31) has suspected a limitation of the standard bacteriological test for coliforms where Pseudomonas organisms occur as contaminants with coliforms in water samples on this basis. The subject merits further study.

3. Clostridium Welchii Toxin. Because Cl. welchii was once suggested by Nelson (32) as a cause of diarrhea and because of the late gas formation noted in Georgetown water samples, experiments were conducted with four

specimens of *Cl. welchii* toxin kindly forwarded by the National Institute of Health. Amounts of each up to 40 ml., diluted to 100 ml. with distilled water, were taken by mouth by a single human volunteer without notable gastro-intestinal effects.

4. *Algal Toxicity*. Blue-green algae have recently been recognized as contributing more than tastes and odors to water. Fitch, *et al*, (33) have emphasized their importance from the point of view of domestic animals. Strell (34) notes the production of cyanide by blue-green algae as a matter of common knowledge, but unfortunately gives no basis for his belief.

Studies of some of the more common blue-green algae were accordingly begun. None was found to have any toxic effect when given to animals by mouth. One--*Microcystis aeruginosa*--was repeatedly found to be lethal for mice and guinea pigs when injected parenterally. The toxicity was greatly increased when the algae were frozen, or frozen and dried in vacuo, for preservation. The toxic substance could be dialyzed and withstood autoclaving so that it was considered to be a chemical poison rather than a bacterial toxin. Dilute solutions remained toxic after coagulation with alum, settling, laboratory filtration, and chlorination, but when comparatively large amounts of carbon were used as an adsorbent the solution was detoxified. When the toxic substance was partially purified and administered parenterally to mice the lethal dose was found to be comparatively small - 0.4 mg. Cyanides were at no time detected in algal material.

VII. Summary of Findings on Water-borne Gastro-Enteritis and Discussion.

The studies of the unit have added their quota to the evidence that a form of epidemic gastro-enteritis is actually water-borne; that there is a definite incubation period of 30-48 hours; that the condition is an infection, not an intoxication; and that such outbreaks may occur with little or no evidence of sewage pollution by standard bacteriological tests of water applied within five days of the time such pollution must have occurred. They have shown that the symptomatology and epidemiology of

at least one outbreak with no evidence of sewage pollution were indistinguishable from one in which evidence of such pollution was found.

The experiments with Berkefeld-filtered sewage have revealed a syndrome in human volunteers which is indistinguishable from that encountered in the field studies of outbreaks. The fact that a careful search was made for accepted pathogens on an assortment of media, and that none were found, clearly indicates that one or more unrecognized organisms may be responsible.

Less conclusive, but highly suggestive, were two other findings from the review of the literature and of the outbreaks observed by the unit: a tendency for outbreaks, where sewage pollution could not be demonstrated, to occur in the late fall or winter months and a tendency for outbreaks to occur after week-ends or holidays when not directly related to repair work on the water treatment or distribution systems.

Inference, duly labeled as such, is more often required in the interpretation of observations on human experience than of purely laboratory findings, because the observation of human experience can seldom be controlled adequately or completed. When the shortage of supervisory staff in most water works on holidays and week-ends is considered, it is not difficult to supply an inference for the aggregation of outbreaks at such times. The maintenance of a high quality of treatment and of uniform distribution cannot be left to automatic controls or to half-staff supervision.

Several questions are raised by the other observations for which solutions can only be provided in the form of hypotheses. The occurrence of outbreaks without evidence of recent sewage pollution brings out the question contained in the deductions mentioned at the end of Section V: Does the agent of water-borne gastroenteritis exist elsewhere in nature than in human sewage, or is the bacteriological test for coliforms less indicative of pollution that may give rise to gastroenteritis than is generally believed?

In this connection a hypothesis can be formulated to explain the various observations noted above in the field studies of the unit and in the reports of others who have explored the subject. A study of the months of onset of outbreaks shows that where the outbreaks resulted

from polluted water they occurred either in winter or in summer. The limited number of coliform-negative outbreaks all occurred in cold weather. The numbers are small in both instances and definite conclusions cannot be drawn. However, there seems a possibility that in cold weather coliforms occasionally may be replaced rather rapidly after they gain admission to water mains by hardier forms which, alone, are found by the time samples are collected and analyzed. With a one to three-day incubation period before gastro-enteritis supervenes and a one to three-day period before investigation is begun, this hypothesis could explain the occasional absence of coliforms in collected samples, if it were known that other organisms found in sewage can displace or overgrow coliforms under conditions of "cold storage". Reports on this subject are rather few but some are suggestive. Parr (35) cites a citrate-utilizing slow lactose fermenting coliform capable of rapidly displacing other types of coliforms in feces stored in the ice box. That certain strains of Pseudomonas do grow readily at low temperatures in well known. The cultures and filtrates of cultures of some of these latter organisms are known to have a bacteriostatic, if not an actual lethal, effect on other microorganisms, and indications are not lacking (31) that the presence of this organism may prevent the identification of coliforms in the standard presumptive coliform tests. Studies at present under way (36) indicate that a considerable preponderance of Pseudomonas is needed to achieve complete suppresion of gas formation, and it may be doubtful whether such a preponderance could have been achieved in the water mains during the short period before the Cohasset, Georgetown, and Coshocton outbreaks came under study.

The above hypothesis is a rather tenuous one but offers some grounds for detailed studies in view of the implication it carries as to the fallibility of the standard bacteriological test to demonstrate pollution in the recent past under cold weather conditions.

According to this view the standard coliform test, if applied at the time of pollution, would still suffice, but cannot be relied upon indefinitely, particularly in the presence of certain other organisms.

What supplementary tests might be employed in the occasional instance where pollution cannot be demonstrated

by standard methods? The laboratory studies suggest two organisms that might be regarded with suspicion until further work exonerates them or implicates one, or both, more definitely -- the Pseudomonas and the spirochaete. Both are apparently present in sewage, both survive fairly drastic filtration.

The above supplementation is not necessary for routine analyses of water quality and is suggested simply as an adjunct of epidemiological study in the rare instances where routine methods fail. Such failure would appear to be due to delayed application rather than to inadequacy.

The implication from the weekend onsets of outbreaks is that present filtration and chlorination standards are adequate for the control of water-borne gastro-enteritis from polluted sources if these standards are consistently met.

VIII. Studies of Diarrhea and Enteritis

As stated in the first section of this report, a further aim of the unit was to determine to what extent the source and quality of the drinking water of communities might contribute to the prevalence of "diarrhea and enteritis", commonly confused with the syndrome described at length in the preceding sections.

For this purpose 144 cities of 10,000 or more population throughout the Ohio River basin were selected. As complete morbidity data for diarrhea and enteritis are non-existent, mortality data were selected to serve the ends of the study. The annual "Mortality Statistics" (37) volumes served as the source of these data. For each of the cities, deaths under the following rubric were taken off for the years 1900-1937. (*) "All causes", "Diarrhea and enteritis" (for all ages, and specifically under 2 years) and "Typhoid fever". In order to obtain annual rates of mortality, population figures for each city were obtained from the decennial census volumes, simple linear interpolation being used to obtain population in intercensal years. Because there were wide fluctuations, particularly in the "D. & E." rates for a given locality from year to year, five-year median rates were derived for

* Certain cities attaining their 10,000 "majority" after 1900 were included where data over a sufficient interval could be obtained.

certain purposes.

Where rates are used as indices of variation, it is customary to apply corrections in order to eliminate effects incidental to the chief cause of variation. Differences with respect to age, sex and color were studied in sample cities and found to involve minor corrections, if any. On the other hand relatively important corrections were indicated in many cities on the basis of residence. Many of the larger cities tended to accumulate patients from surrounding rural areas or nearby smaller cities, (hereafter called "satellite cities") with the result that rates for the former were unduly high. In the satellite cities of the study, on the other hand, rates were often unduly low--sometimes actually zero for quite long periods. The residence death correction could not be made specifically for diarrhea and enteritis deaths -- no such data being available -- but was based upon deaths from all causes from 1937 and 1938 "Mortality Statistics" data on resident and non-resident deaths from all causes in each city.

It is recognized that the rubric "diarrhea and enteritis" is so comprehensive that a subclassification would be highly desirable. It probably includes a great many conditions quite incidental to infectious, or even to non-infectious, conditions of the intestinal tract and it does not include all dysentery deaths, which would be highly pertinent to the investigation at hand. However, deaths specifically classed as dysentery were so few that their omission from the rates was found to make unimportant changes, and this item was accordingly omitted. Actually most of the severe or fatal cases classed as "D & E" have been found to be undiagnosed dysentery. One of the important causes of diarrheal death in the South is probably undiagnosed pellagra -- a point which should be carried in mind when the relatively high rates in this region are being considered. However, dysentery deaths are also more frequent in the South than in the North and undoubtedly still constitute the bulk of the deaths from D & E.

The method of the study consisted in comparing the rates for groups of cities, each group differing with reference to some important aspect of water source or treatment. Comparison was also made between typhoid

fever and diarrhea and enteritis rates in order to determine whether the installation of various improvements in water treatment might have affected one more than the other. Finally certain detailed studies were made of water quality in relation to diarrhea and enteritis mortality in individual communities.

In general, there are two sources of urban water supply; well water, hereafter called ground supply, and surface water from streams, creeks and rivers. Many cities, however, have both, using one or the other as supplementary source or continuously use the two in combination. Enough cities used these combined supplies to warrant a third category hereafter referred to as "mixed supply".

Table 1.

Averages and medians of the 1933-1937 mean diarrhea and enteritis death rates per 100,000, of cities in the Ohio River Basin, as a whole and by regions, according to source of water supply.

Area	Surface	Mixed	Ground
A - Averages of Mean Rates			
Total O.R.Basin:	21.6	14.3	19.0
Northeast	12.3	11.1	11.3
Northwest	26.4	19.8	22.5
South	39.0	28.4	33.5
B.- Medians of Mean Rates			
Total O.R.Basin	13.7	15.4	16.0
Northeast	11.6	10.4	11.2
Northwest	20.3	18.7	21.3
South	33.0	28.4	35.8

For a comparision of rates in cities using these three categories of water, the annual rate for diarrhea and enteritis for each city over the period 1933-1937 was derived, and the mean rates for all the cities in each group were averaged to obtain a mean rate for the group. The comparison is shown for cities in the Ohio River Basin in the first line of Table 1.

The variation between rates in individual cities of the Basin is very marked. It is often quite extreme when the rates for adjacent cities are compared. This subject will be discussed at greater length below. However, in general the rates tend to be lowest in the northeastern section (southern New York, western Pennsylvania, eastern Ohio). They become higher in the northwestern section (western Ohio, Indiana and eastern Illinois) and tend to be very high in the southern section (West Virginia, Kentucky, Tennessee, northern Alabama). Ground water supplies are more frequently used in the two northern sections and surface water supplies more commonly in the South. There is, however, a fair number of both in each of the regions so that a regional comparison would appear to be indicated. This has been made in the next three lines of Table 1. Here, only a slight excess mortality appears in the cities using surface supplies when compared with those using mixed or ground supplies. The variation by region is seen to be quite striking -- averages for the Northwest and for the South being about double and triple, respectively, those for the northeast in each category. Mixed supplies tend to show lower rates than either ground or surface, but there are relatively few of these.

Because even the mean rates for cities over a five-year period show rather wide variation, the median offers perhaps a better basis for comparing these rates than the average. The second part of Table 1. shows median data for the same groups of cities. Here very little difference appears between the various sources of supply; the basic difference is again unquestionably the regional one.

Ground water supplies in general are considered less subject to pollution than surface supplies. Like all generalizations, this has its exceptions, but it

holds true.

A further study, supplementary to the above, was made of the variation in mortality from diarrhea and enteritis with variation in the quality of raw water for cities using surface supplies. The D & E deaths in individual cities were compared with the monthly average figures for the M. P. N. of coliforms, and plate counts, in the raw water of individual cities using surface water as a source of supply over a considerable period of years. Such data were available for Cincinnati, Ohio, and for Louisville, Kentucky. In general the coliform M. P. N. and plate counts tended to run low in the summer and higher in the winter in the raw water of both of these cities, while the D & E deaths were concentrated in the summer months and declined notably with the onset of cold weather. On a monthly basis, therefore, no definite relationship could be found between the quality of the raw water as indicated by the M. P. N. of coliforms and the plate counts.

A final comparison--that based on the quality of treated water--would be perhaps more pertinent to the present study. However, very nearly all of the 144 cities consistently met the U. S. Public Health Service standard over the period 1933-1937 and little basis therefore exists for the establishment of subdivisions based on treated water quality. A majority of cities also used equipment and techniques of water treatment of a sufficiently high order so that grading them upon such a basis would entail division into groups differing in such minor respects as to be unimportant.

One of the early proofs that typhoid fever in cities was traceable to polluted water supplies, was obtained by the demonstration of consistently, and often strikingly, low rates following the installation of water treatment procedures, such as filtration and chlorination. Typhoid fever death rates prior to and subsequent to the water treatment installation formerly were compared and decreases in the latter as compared with the former were noted with enthusiasm. The same favorable effect was often discernable in the death rate for all causes (Mills-Reinecke phenomenon). The effect on the typhoid fever rates was often definite and unmistakable. The effect on the general death rate was less clear-cut, and it was soon recognized that, where a rate was consistently declining--

as the general death rate from all causes was declining in most cities during the latter part of the nineteenth and in the early part of the twentieth centuries -- some decrease inevitably occurred when the rate for a later period was compared with that for an earlier period.

The effect of the installation of improved water treatment methods on the typhoid fever death rate seemed definite enough, however, to provide a guage for the extent in which diarrhea and enteritis deaths may have been, to former year, ascribable to water. With this in view, three groups of cities using surface water supplies and beginning water treatment in the interval 1905 to 1933 were studied in detail. The first group consisted of seven cities (Table 2) instituting filtration and chlorination in combination. The second contained 14 cities (Table 3) where filtration was started independently of, and usually prior to, chlorination. The third contained 22 cities (Table 4) where chlorination was begun independently of, and usually subsequent to, filtration. Groups 2 and 3 contain many cities in common. diarrhea and enteritis mortality rates were computed for individual years for the five years preceding and the five years subsequent to the installation of treatment (omitting the year in which treatment was begun). Because the D & E rates show a consistent downward trend over the whole interval 1900-1937 it was to be assumed that the subsequent interval would show lower rates whether water treatment was related to D & E mortality or not. As a control, similar rates for typhoid fever mortality were computed for comparison with those of D & E.

Averages of the five-year annual rates for the periods before and those after installation were at first used, but variability in these intervals prompted the use of the median rather than the mean. Both methods were in essential agreement, so the median rates were selected for presentation. The resulting tables show the median D & E and typhoid fever mortality rates for the two intervals before and after beginning treatment as follows: Table 2, cities beginning filtration and chlorination in combination; Table 3, cities instituting filtration separately; Table 4 cities instituting chlorination separately.

It will be observed that the five-year median rates for cities in the first group (Table 2) uniformly

Table 2

Median mortality rates per 100,000 for Typhoid Fever and for Diarrhea and Enteritis for the five-year periods before and after combined Filtration and Chlorination in seven cities using surface supplies.

City	Median D & E Rates 1-5 years before	Median D & E Rates 1-5 years after	Ratio After/Before	Median Typhoid Fever Rates 1-5 years before	Median Typhoid Fever Rates 1-5 years after	Ratio After/Before
Logansport, Ind.	70.3	34.4	0.49	37.9	34.0	0.90
Cambridge, O.	50.0	39.8	0.80	40.3	7.8	0.19
E. Liverpool, O.	104.2	61.0	0.59	76.6	32.8	0.43
Ironton, O.	93.9	45.5	0.48	65.9	13.0	0.20
Portsmouth, O.	94.1	90.5	0.96	70.9	28.3	0.40
Steubenville, O.	156.3	143.0	0.92	67.8	22.0	0.32
Wilkinsburg, Pa.	93.3	35.0	0.37	47.6	18.0	0.38

Table 3

Median Mortality Rates per 100,000 for Typhoid Fever and for Diarrhea and Enteritis for the five-year periods before and after filtration in 14 cities using surface supplies.

City	Median D & E Rates 1-5 years before	D & E Rates 1-5 years after	Ratio After/Before	Median Typhoid Fever Rates 1-5 years before	Typhoid Fever Rates 1-5 years after	Ratio After/Before
Anderson, Ind.	91.1	68.9	0.76	72.7	28.1	0.39
Evansville, Ind.	87.3	75.1	0.86	34.1	23.6	0.69
Indianapolis, Ind.	123.2	73.4	0.59	43.5	31.3	0.72
New Albany, Ind.	60.9	53.9	0.89	23.4	18.1	0.77
Louisville, Ky.	72.8	52.0	0.72	63.6	26.7	0.42
Paducah, Ky.	203.2	81.5	0.40	85.2	65.3	0.77
Bellaire, O.	110.5	48.5	0.44	36.2	20.5	0.57
Cincinnati, O.	109.2	99.9	0.91	61.2	13.3	0.22
Columbus, O.	60.1	55.2	0.92	35.8	18.8	0.52
Marietta, O.	52.8	53.6	1.02	98.0	23.1	0.24
Youngstown, O.	115.9	169.9	1.47	123.7	36.3	0.29
McKeesport, Pa.	196.8	159.4	0.81	107.1	32.5	0.30
Wilkinsburg, Pa.	93.3	46.2	0.50	47.6	34.0	0.72
Nashville, Tenn.	55.1	35.8	0.65	16.1	7.7	0.48

Table 4

Median Mortality Rates per 100,000 for Typhoid Fever and for Diarrhea and Enteritis for the five-year periods before and after Chlorination in 22 cities using surface supplies.

City	D & E Rates Median 1-5 years before	D & E Rates 1-5 years after	D & E Ratio After/Before	Typhoid Fever Rates Median 1-5 years before	Typhoid Fever Rates 1-5 years after	Typhoid Fever Ratio After/Before
Evansville, Ind.	75.1	32.2	0.43	23.6	4.5	0.19
Indianapolis, Ind.	73.4	68.0	0.93	31.3	24.0	0.77
New Albany, Ind.	53.9	38.7	0.72	22.2	4.3	0.19
Terre Haute, Ind.	111.8	83.2	0.74	37.1	24.4	0.66
Vincennes, Ind.	75.1	54.0	0.72	25.4	24.4	0.96
Louisville, Ky.	52.0	50.2	0.97	24.0	14.4	0.60
Paducah, Ky.	81.5	76.4	0.94	60.5	24.8	0.41
Asheville, N. C.	58.7	48.3	0.82	18.3	7.6	0.42
Bellaire, O.	116.1	47.6	0.41	20.5	7.0	0.34
Cincinnati, O.	110.3	77.1	0.70	13.3	6.6	0.50
Columbus, O.	47.6	38.0	0.80	13.9	4.5	0.32
Marietta, O.	28.5	33.5	1.17	29.9	20.4	0.68
Newark, O.	42.9	44.4	1.04	35.1	7.4	0.21
Springfield, O.	41.6	30.3	0.73	26.2	6.4	0.24
Warren, O.	49.0	73.9	1.51	28.6	33.3	1.16
Youngstown, O.	14.2	8.3	0.58	1.2	1.2	1.00
Beaver Falls, Pa.	133.6	103.5	0.78	16.7	48.0	2.87
Du Bois, Pa.	80.4	40.2	0.50	14.7	7.6	0.52
McKeesport, Pa.	159.4	82.7	0.52	32.2	10.8	0.34
New Castle, Pa.	124.0	83.7	0.68	48.4	21.7	0.45
Uniontown, Pa.	79.6	81.3	1.02	97.7	59.1	0.61
Wilkinsburg, Pa.	68.7	35.2	0.51	45.7	18.0	0.39

fell for the interval after the treatment as compared with those for the period before treatment. However, the decline was not as marked (as shown by higher ratios) as in the case of typhoid fever.

The same is true of Tables 3 and 4 although here, occasionally, higher median rates for both D & E and typhoid fever are evident in the post-treatment interval.

Mean ratios for D & E in the three groups are 0.66, 0.72 and 0.78 respectively. This means that the median rates subsequent to treatment were between two-thirds and three-quarters of the median rates prior to treatment. Typhoid fever on the other hand shows more consistent decreases. Here mean ratios for the three groups were, respectively, 0.40, 0.51 and 0.63. A review of the ratios, city by city, will show that marked decreases in the D & E rates (as shown by low ratios) are not necessarily accompanied by similar decreases in typhoid fever and <u>vice-versa</u>.

The tentative conclusion is that improvement in the safety of drinking water by water treatment in cities of the Ohio River watershed did not affect the D & E mortality to the extent that these improvements affected the typhoid fever mortality. A detailed study of trends would be needed to establish this point more definitely. The era in which these improvements were begun (largely between 1905 and 1925) was one of great activity in environmental sanitation generally. Water treatment was but one of these activities; simultaneously privies were abolished with the extension of sewage systems, garbage was collected and burned or buried, livery stables disappeared, and foods were safeguarded.

Limited as the foregoing observations have been to D & E mortality, they do not rule out the possibility of a considerable morbidity with low mortality in cities with water as the vector. They simply indicate that the mortality listed under the rubric "Diarrhea and Enteritis" is but little influenced in <u>recent years</u> by the source of the water supply when adequate treatment is applied.

These essentially negative mortality findings would be more conclusive if real relationships with other sources or vectors could be demonstrated. Other relationships were sought and suggestive leads were found, though

no definite conclusions were drawn.

Forming, as dysentery does, a notable proportion of the severe deaths attributed to D & E and being, as dysentery is, a disease of poverty, it might be expected that economic factors are of importance in the distribution of D & E deaths. Such a hypothesis might well be evolved to explain the prevalence of this group of diseases in the South, and in the crowded sections of the larger cities. However, no clear-cut relationships between D & E death rates, city by city, and various economic indices (income tax payments, magazine sales, etc.) could be found.

Very definite was the relationship between latitude and D & E mortality for cities in the Ohio River Basin. A subsidiary relationship here was found to be altitude. With few exceptions cities located at higher altitudes enjoyed more favorable rates than those at lower altitudes but in the same latitude. This factor was found to explain some, but not all, of the variation between neighboring cities.

These findings suggested that climatic factors may be of importance. A very considerable and conflicting literature on the relationship of diarrhea and enteritis mortality and climate exists, which will not be possible to review here. The studies of the unit on climate in relation to diarrhea and enteritis covered a wide variety of localities. It was noted that D & E deaths when studied for individual states, by months, tended to show fairly narrow, elevated peaks in the late summer (August and September) in the northern states, while the peaks came earlier (May-June) in the southeastern states and tended to have a broader base. In the states of the continental U. S. precipitation is fairly constant throughout the year but temperature varies markedly. The reverse is true in Porto Rico and Hawaii where temperature remains throughout the year at levels reached only in summer in the United States but where rainfalls vary considerably. In Hawaii the rains, according to rather fragmentary data for Honolulu, occur in what would be the winter months. In Porto Rico there are two periods of rain, one in summer and one in winter. D & E mortality is surprisingly high throughout the year in both these localities but small peaks

of mortality frequently occur after the rains--which are seldom excessive. The relationship is not a direct one because the mortality maxima tend to follow the peaks of rainfall after an interval of a month or more and do not coincide with them.

When the climatic and monthly mortality record of individual cities of the Ohio River Basin is studied over a long time interval, it is apparent also that hot and rainy summers show a greater D & E mortality than hot and dry (or cool) summers. There appears, then, to be some relationship between this disease and both temperature and precipitation. The lag in the relationship to both temperature and precipitation is, however, noteworthy, and may help to explain some of the negative reports on these factors in the literature where an attempt was made to relate deaths and simultaneous climatic conditions.

Further evidence that the climatic factors are indirectly related is obtained from a comparison of rates for cities not widely separated geographically, yet similar from the point of view of altitude and non-resident deaths. Some will consistently run higher than others. Upon investigation the former will often be found to have water supplies comparable with those of the latter but other sanitary provisions, notably, (sewage and waste disposal) will be found less adequate.

The delayed relationship with climatic factors and the observations just noted give some encouragement for the hypothesis that the housefly--fallen into discredit of recent years as a disease carrier--may actually play something of a role as a vector for some of the diseases included in the broad category of diarrhea and enteritis. Undoubtedly the remainder of the famous complex of food, fingers, and flies, plays some role, aided and abetted by improper care of food (inadequate screening and refrigeration) both at the source of supply, in urban distribution centers, and in the home.

Field observations were made upon diarrheal outbreaks on more than one occasion. They appeared throughout the summer primarily in the form of individual household outbreaks, without the close relation between onsets in other attacked households noted in the

explosive water-borne gastro-enteritis epidemics. Children were attacked more frequently and severely than adults, and the mortality tended to be far higher than with gastro-enteritis.

A somewhat puzzling fact about diarrhea and enteritis is that the mortality is considerably higher in male than in female children -- a fact commented upon by Bakwin (38), Hosoi & Alvarez (39) and by Ciocco (40).

In this male preponderance, as in the age and seasonal distribution of cases, there is a close analogy with infantile paralysis. This analogy is even beginning to have regional aspects within the continental United States, at least.

An opportunity for the intensive field study of one diarrhea and enteritis outbreak was presented when the unit was asked to collaborate on the field and laboratory study of an outbreak with a relatively high mortality (117 cases and 12 deaths) in Adair County, Kentucky. With examinations conducted upon fresh stools, a surprisingly high proportion proved to have bacillary dysentery of the Shiga type. The outbreak was at first confined to homes on the outskirts of Columbia, the County seat, beyond the limits of the town water supply where privies (seldom used by the younger children) and poor sanitary conditions of the homes themselves were noted. Well water supplying these homes was found to be polluted, but there was little relation between the onset of cases in homes using water from the same well, and many homes escaped entirely. A survey of non-attacked homes in this area revealed better screening against flies, more meticulous housekeeping and better protection of the food between meals. As the epidemic progressed occasional cases were noted in the better type of home but only three cases occurred in homes supplied with running water from the town system. Cases also began to occur on more or less distant farms -- often after family visits to or from homes in the stricken area -- and outlying foci were set up from which the disease spread to adjacent farms.

Cases occurred at all ages, but children tended to be attacked more often than adults, and the fatal cases were all under eight years of age. Males were

more often attacked than females. The mortality was also greater among males, but the case fatality was the same for both: a point of some interest in connection with the sex differences in mortality noted above.

The outbreak of Shiga dysentery in Adair County started in the latter part of May and lasted throughout the summer -- a prolonged affair in comparison with the epidemics described earlier in this section of the report. (See Appendix IV)

While the role of flies in the dissemination of this disease may have been a minor one, it is evidence that the epidemiological picture is hardly that of a water-borne epidemic.

This and other studies made above tend to sustain the view that the role of water as a factor in the mortality complex "Diarrhea and Enteritis" is a negligible one where present standards of water quality are met and maintained continuously.

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APPENDIX I.

Form used in Field Study

WATER-BORNE DISEASE STUDY

ADDRESS_______________________; White___ Colored___; Church___________________

Check person (s) interviewed.		Name	Sex	Age	Date First attk'd	Hour First attk'd	SYMPTOMS					Place of occupation or school	Visits away from home during period of outbrk	Water used for drinking
							Naus	Vom	Cramp	Diarrh	Other			
	1		M F											
	2		M F											
	3		M F											
	4		M F											
	5		M F											
	6		M F											
	7		M F											
	8		M F											
	9		M F											
	10		M F											

Guests or visitors present during period of outbreak but now left: ____________________Address__________

Date arrived __________Date left __________

Household
Water Supply: City___Well___Cistern___Spring___Other___
Comments on quality of water during period preceding outbreak:
Taste_______ Odor_______ Color_______ Turbidity_______ Other_______

Milk Supply: Source__________________ Comments on quality of milk____________________

Food, Baked goods, eclairs, door to door delivery:

____
____
____
____

Space for special questions and for extension of remarks above:

____
____
____
____

Date Interviewed__________Interviewer____________________Cooperativeness__________ (Over)

<u>APPENDIX II.</u>

<u>Gastro-enteritis Outbreak in Georgetown, Kentucky</u>

Epidemiological Study of Water-borne Gastro-enteritis in Georgetown, Kentucky

by
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On the 16th, 17th and 18th of November, 1940, a strikingly high prevalence of gastro-enteritis in the city of Georgetown, Kentucky came to the attention of the Scott County Health Department. Preliminary studies made by that Department indicated that the water supply might have been the source of the trouble. The superintendent of the water treatment plant was asked to increase the amount of chlorine in the city water, and this increase was started at noon on the 18th. The State Department of Health was also notified, and, through the latter's cooperation, the outbreak came to the attention of the Water-borne Disease Study Unit of the Ohio River Pollution Survey on the afternoon of Monday, November 18th. An intensive study of the outbreak was begun on the morning of Tuesday, November 19th.

The study was divided into three broad types of inquiry; (a) a house-to-house canvass of a sample of the population to determine the incidence and distribution of the disturbance and its vehicle; (b) laboratory studies of the suspected vehicle and of patients to determine, if possible, the primary cause; (c) environmental studies of a sanitary character. The present report will deal primarily with the results of the first two of these, the last having been covered in an early separate report owing to the urgency of the need for correcting some of the conditions disclosed.

Results of the House-to-house Inquiry

When questioned as to the character of the illness it was usually described as an acute diarrhea with severe "cramps" and often accompanied by either nausea, vomiting, or both nausea and vomiting. During the canvass 131 cases were discovered, the detailed symptomatology of which is given in Table 1.

Table 1.

Symptons Described for 131 Cases of Gastro-enteritis, Canvassed Populations, Georgetown, Ky.

Sympton	No. of Cases
Diarrhea Alone	26
Diarrhea and Cramps	61
Diarrhea, Cramps, Nausea or Vomiting	29
Cramps Alone	15
Total	131

In general the duration was given as "a day or two" but a few cases lasted three or four days. In about 10 percent of the cases it was noted that the initial attack subsided in one or two days but relapse occurred with quite violent watery diarrhea lasting another two or three days as though the first attack had paved the way for secondary invaders.

The dates of onset obtained by canvass and by questionnaires addressed to 136 college students are shown in Table 2.

Table 2.

Dates of Onset of Cases of Gastro-enteritis in the Canvassed Population of Georgetown, Ky., and among Students of Georgetown College, November, 1940.

Group	Dates of Onset											
	Prior to Nov. 14	14	15	16	17	18	19	20	21	22	Unknown	Total
College Students	6	3	25	31	26	11	6	-	-	-	3	111
Georgetown Proper	4	3	5	25	30	29	14	9	2	4	6	131
Total	10	6	30	56	56	40	20	9	2	4	9	242

A limited number of cases occurred in Georgetown College after the 19th - the day on which the questionnaire was submitted. Canvassing continued in the city until the end of the week, by which time it was possible to obtain accurate dates of onset for only a few recent cases.

Cases were not uniformly distributed throughout the city, but tended to be concentrated in the better residential districts and in the college. One section of small dilapidated homes inhabited by colored day-laborers escaped entirely, although almost surrounded by a better class of residential homes which were heavily attacked. This poorer section had practically no running water in the home, being supplied almost entirely by small hydrants on the city water supply located near street intersections. Canvassing in this section was quite unsuccessful during daylight hours because few people were at home. The freedom from attack was not wholly racial because colored families up-town where the prevalence was high showed practically the same incidence as the neighboring white families.

The age incidence of the malady was nearly uniform for the various decades of life and is shown in Table 3. There is seen to be no concentration of cases in the younger ages so characteristic of milk-borne outbreaks and of the summer diarrheas. Also against the hypothesis that milk served as the vehicle was the fact that the incidence among those taking from all six of the city's principal milk sources, including one distributing adequately pasteurized milk, was very nearly uniform.

Table 3.

Age-Incidence of Gastro-enteritis Among the Canvassed Population of Georgetown, Kentucky.

Age (Years)	Total Canvassed	Total Attacked	Percent Attacked
Under 2	9	1	11.1
2 - 9	53	10	18.9
10 - 19	101	19	18.8
20 - 29	70	29	41.4
30 - 39	49	13	26.5
40 - 49	57	19	33.3
50 - 59	52	15	28.8
60 - 69	42	19	45.2
70 Plus	25	5	20.0
Not specified	6	1	16.7
All ages	464	131	28.2

Food was bought at a diversity of stores by the various households. There was only one door-to-door food vending agency - a bakery wagon from an adjacent city. The largest part of the sales for this wagon consisted of bread and rolls, and many attacked households reported not buying from this agency at all.

The true incidence of the malady in the population of Georgetown was probably considerably above the figure of 28.2 percent shown for all ages in Table 3 for reasons which will presently be given. So high an incidence could only be explained on one of two hypotheses; first that the vehicle was the town water supply, or second, that an exceedingly infectious virus was spread from person to person as influenza is now considered to be spread.

That the first of these seems more likely is suggested by the incidence among those habitually drinking city water compared with the incidence where it was not habitually taken. Nearly all of those using wells or cisterns for their drinking water supply in Georgetown were interrogated in the house-to-house canvass.

Table 4.

Incidence Among Canvassed Persons in Georgetown Using City Water and Among Those Habitually Using Private Well and Cistern Water.

Source of drinking water	Canvassed	Attacked	Percent Attacked
City Water	388	119	30.6
Other Sources	76	12	15.8

The significance of the difference between the two percentages in Table 4 is considerably enhanced by the fact that for eleven of the 12 persons who were attacked, despite the habitual use of other sources of drinking water, it was possible to obtain a history of fairly liberal use of city water while working or visiting outside the home. Had the disease been an air-borne virus there should have been no such marked discrepancy as that shown in Table 4 between two groups of Georgetown residents.

In addition to including a nearly complete tally of persons using other sources of water supply, Table 4 contains a disproportionately large number in the colored section above mentioned where the incidence was found to be very low. The residential section about Georgetown College and the college itself were the sections where the disorder was most prevalent. Questionnaires filled out by students at the college showed 109 or 80 percent attacked. This whole section of the city was covered by canvass much less completely than other areas. For these reasons the incidence for the city as a whole must be regarded as far higher than the figures shown in Tables 3 and 4. A reasonable estimate would be a figure not far from 50 percent.

During the course of the canvass a number of statements were obtained about the simultaneous prevalence of the disorder among persons on outlying farms, in adjacent cities and even in remote centers. These were investigated, so far as time permitted, and usually turned out to be unfounded or based upon the fact that an illness had occurred which was not the same as that experienced by the residents of Georgetown. Occasionally the true version offered a startling confirmation of the waterborne hypothesis. Not a few cases closely resembling those in the city were encountered on outlying farms as sole cases in large households. Upon questioning it was usually found that the patient had visited Georgetown a few days prior to the attack and some of them could recall having ingested nothing but water while in the city. Where the date of visit and date of onset seemed to be remembered accurately these cases were used to establish incubation periods for the disorder. One case had an onset within twelve hours after a fifteen minute stopover in Georgetown during which he had taken a glass of water and a ham sandwich. A patient in the Georgetown Hospital was discharged to his farm home on the 17th and developed a typical attack on the 20th. Another patient who visited Georgetown briefly on the 16th was attacked on the 18th. Forty-two students from an Indiana college attended a football game with Georgetown College on the 16th at Georgetown. The day was cold and many, even of the players, denied having taken any water during their six hour stay in Georgetown. However, sixteen recalled having taken varying amounts of water; only three drank freely, the others having had one glass or less. Four cases of gastro-enteritis occurred and all four occurred among the sixteen students with a history of having taken water. All but one had also eaten ice cream or "hot dogs". The other recalled having had nothing but water during his stay. The onsets were on the 17th, 18th, 20th and 21st. The player whose onset occurred on the 17th broke training after the game and may have had other causes for his attack of vomiting and diarrhea.

A number of people were questioned as to whether they had noted any abnormal tastes or odors in the water during the week prior to the outbreak, and several answered that the water was unusually malodorous toward the end of the week. The odor was noted particularly on opening bottles of water kept for some time in the refrigerator. Few could describe the quality of the objectionable smell or taste but one intelligent response was that it smelled and tasted "like rotten wood".

Summing up the results of the house-to-house study, then, the evidence strongly indicates that water was the vehicle by which this infection or intoxication was distributed in Georgetown. That it was more probably an infection than an intoxication is evidenced by the two to three day incubation period of the few cases having a short enough exposure in the city to justify drawing a conclusion. The agent was probably in the water as recently as Saturday afternoon, November 16.

Laboratory findings.

During the latter part of the week of November 11th a peculiar blue-black tint was noted in the water of the Royal Spring from which Georgetown receives its water supply. In the settling basins this color was particularly noticeable where the water was not completely obscured by floating masses of decomposing algae. It may be that the latter contributed some of this color for it was noted that the water in bottles in which some of these algae were collected was tinted quite deep blue after standing. The plant masses were found to be largely composed of a species of *Oscillatoria*. The odor of these samples was very unpleasant and the taste much like that of "rotten wood". Some of this material was autoclaved and ingested with no ill effects. It cannot be said that the algae were entirely incidental to the outbreak, however, for it seems likely that in decomposing they at least added to the organic load of the water. This would help to explain one of the first of the laboratory findings which was that, although the chlorine feed had been markedly increased at noon on Monday, November 18th, no residual chlorine was detected in any of the samples taken at noon the following day with but a few hours detention of treated water at the plant.

Before detailing the bacteriological analyses of the water at the time of the outbreak it may be useful to present the results of the routine analyses of treated city water as shown by the State Health Department Laboratory reports on file in Georgetown for the entire year of 1940. These are detailed in Table 5.

Table 5.

Total Bacterial Counts (37°) and Percentage of Gas Formed in Lactose Broth at 48 Hours in Routine Analyses of Georgetown Water Samples for the Year 1940

Date		Total Count, per cc.	Percent Gas Formed
January	10	5	0
	17	0	0
	24	9	0
	31	9	80
February	7	21	60
	9	108	10
	14	3	0
	21	1,144	0
	28	954	0
March	6	572	0
	10	8	0
	13	508	0
	20	8	0
	27	2	0
April	3	3	0
	10	5	100
	17	1,144	(a)
	24	0	0
May	1	Over 10,000	20
	8	0	0
	21	(b)	(b)
July	10	5	0
	16	572	0
August	1	5	0
	14	2,163	0
	21	954	0
	28	9,158	0
September	4	4	0
	11	(c)	(a)
	17	2	0
	25	2	0
October	2	Over 10,000	0
November	8	5	0
	18	28	90
	20	4	0
	25	2	0
December	2	84	0
	4	0	0
	16	3	0

(a) No record on gas formed.
(b) Four samples from various points showing total counts of 0 or 2 and no gas.
(c) Colored school - 1271; Garth school - 954

There is evidently a very substantial variation in the total count and at times extensive gas formation is noted in the presumptive broth tubes after 48 hours, though the degree to which this latter would confirm is not given. Unfortunately, no sample was sent to the laboratory during the week preceding the outbreak (November 10 to 16). The samples were taken at a tap at the water treatment plant. Some of the variation in total count may be explained on the basis of faulty operation of the filtration plant. However, a decided variation in total count and marked turbidity in the raw spring water is known to occur a few days after heavy rainfall over the collection area feeding the spring. A light drizzling rain had fallen in Georgetown on Armistice Day, five days before the outbreak. There was reason to believe that the rainfall had been heavier south of the town in the region from which the spring receives its water, as the flow was augmented markedly and the water became turbid just prior to the onset of the epidemic. During the ten days following the rain the temperature fell below the freezing point several times.

The first samples available for bacteriological study after the outbreak began were taken by the County Health Department at noon on November 18th, kept overnight on ice and analyzed the following day. The results of examining these samples - taken at scattered points on the main grid of the distribution system are shown in Table 6a. The results of a second set, taken in all but one instance from similarly scattered but slightly different points on the main grid on the following day, are given in Table 6b. The results of a third set taken chiefly from dead-ends on the same day as those in Table 6b (November 19) but studied in a somewhat different manner are given in Table 6c. On the 19th after taking these samples (which showed no residual chlorine despite the increased feeding of chlorine the previous day) the dose was again increased and a residual began to appear in the mains toward evening. Samples taken subsequently showed a heavy residual and were practically sterile.

Except for evidences of high content of gas-forming bacteria, the figures for all but one of the samples of Table 6 show a fairly good grade of water; certainly not one which is polluted in the accepted sense of the term. The findings for sample No. 17 are not easily explained except on the basis of contamination at the time of taking the sample.

The remarks on gas formation in these samples should be amplified. In no case did gas appear in the presumptive tubes during the first 24 hours of incubation. In the second and

Table 6

Results of Treated Water Sample Analyses, Georgetown, Kentucky, November 18 and 19

Sample Station Number	Total Count at 37° per cc.	MPN of coliforms per 100 cc. confirmed	Remarks
			a. Samples of November 18 /x
1	600 /z	Less than 2.2	No gas formation.
2	25	" " 2.2	48 hr. gas formation in three of five 10 cc. presumptive tubes not confirming.
3	5	" " 2.2	" " " " " one " " " " " " " "
4	25	" " 2.2	" " " " " two " " " " " " " "
5	10	" " 2.2	" " " " " four " " " " " " " "
6	5	" " 2.2	" " " " " four " " " " " " " "
7	10	" " 2.2	" " " " " all " " " " " " " "
			b. Samples of November 19 /x
3	10	Less than 2.2	48 hr. gas formation in three of five 10 cc. presumptive tubes not confirming.
8	10	" " 2.2	No gas formation.
9	800 /z	" " 2.2	" " "
10	40	" " 2.2	48 hr. gas formation in two of five 10 cc. presumptive tubes not confirming.
11	5	" " 2.2	No gas formation.
12	10	" " 2.2	" " "
			c. Samples of November 19. (Specially studied) /y
13	160	Less than 1	48 hr. gas formation in seven of ten 10 cc. presumptive tubes not confirming.
14	20	1	" " " " " six " " " " " " " " (One tube partially confirmed)
15	10	Less than 1	48 hr. gas formation in one of ten 10 cc. presumptive tubes not confirming.
16	25	1	" " " " " four " " " " " " " "
17	10	16	" " " " " ten " " " " " " , 7 confirmed.
18	20	Less than 1	" " " " " nine " " " " " " not confirming.

(x) Five 10 cc. lactose broth tubes used for presumptive test. Partial confirmation by 2% Brilliant Green Bile broth and MacConkey's agar.
(y) Ten 10 cc. lactose broth tubes used for presumptive test. Partial confirmation as above.
(z) Estimated number.

third samples of Table 6a it showed in relatively small amounts; in the fourth, fifth and sixth samples one tube of each set showed explosive gas formation. Fewer samples of Table 6b tended to show gas but here again one tube of each set showed explosive development. The general distribution of gas formation among the dead-end samples of Table 6c more nearly resembles that for those taken on the main grid the previous day (Table 6a), and here also it was explosive in about the same ratio.

Detailed attention has been given to these findings on late gas-formation because they represent a common finding in connection with gastro-enteritis outbreaks and suggest the presence of anaerobes which may not be present in large numbers but nevertheless may be etiologically related. Apparently the use of anaerobic culture methods on samples of water suspected of causing gastro-enteritis is basically indicated but was, unfortunately not resorted to in the present study.

The samples of Table 6c were studied in more detail than can be shown there. Tubes showing no gas were streaked on plates of MacConkey's medium and suspicious colonies fished for further study. In addition two 100 cc. portions of each sample were filtered by suction through discs of diatomaceous earth in Jenkins filters, the two discs being planted in tubes of lactose broth and Selenite F media, respectively, for enrichment. After 24-48 hours the tubes were streaked on MacConkey's plates and suspicious colonies again fished.

By these methods five of the six samples were found to contain bacteria of the genus Pseudomonas. One sample contained this organism alone, the other four contained also bacteria of the genus Alkaligenes. The one sample from which no cultures could be obtained came from a dead-end at a C.C.C. camp nearly a mile out of town where no cases occurred, despite the use of city water.

The study of individual patients gave no further clue to the etiology. The symptomatology has been briefly outlined above. Fever was slight or absent. One blood culture was secured and proved sterile. The blood of six patients was studied microscopically: five showed white blood cell counts ranging from 5,000 to 7,000 and one showed a white count of 12,500. The differential count was uniformly within normal limits.

Six stools freshly passed, were studied microscopically: three showed considerable numbers of a small yellow cell not much larger than a red cell but oval in outline and not dis-

solving in acetic acid. Presumably these were small yeast cells. The remainder showed no abnormality.

Twenty stools were examined bacteriologically within three hours of passage, on the following media; MacConkey's agar, Desoxycholate citrate agar, Salmonella-Shigella agar and Bismuth-Sulphite agar. In addition some of each stool was inoculated into Selenite F enrichment medium and subsequently streaked on MacConkey's agar. Eighteen of the twenty showed a rather sparse growth of the usual coliform colonies. One showed a nearly pure culture of Pseudomonas and one showed colonies which gave the cultural reactions of a Salmonella. Through the courtesy of Dr. P. R. Edwards of the University of Kentucky, Lexington, this organism was finally identified as Salmonella panama. Of the eighteen stool specimens showing the usual coliform flora seven also showed other types of colonies. These, on further study, were found to be coliforms in five instances, Pseudomonas in two and Proteus in two. One stool containing Proteus and one containing Pseudomonas also had colonies later found to be coliforms.

Only one organisms, Pseudomonas, was obtained from both the water and the stool samples and this was found inconstantly in the latter. Despite the inconstancy of its appearance in the stools it seemed advisable to study this organism in some detail. It was formerly regarded as one of the causes of intestinal tract infection; it is known to produce a rather complex toxin fatal to experimental animals when injected subcutaneously. Lacorte, in Brazil, recently described diarrheal death in animals when comparatively small doses of culture filtrates are injected into the duodenum. It is known, also, that the organism can produce cyanide in small amounts of culture. There has recently been a recrudescence of interest in this group as one of the causes of diarrheal disease, if not of gastro-enteritis.

Studies in our laboratory, which have not as yet been completed, do not, however, support the view that either filtrates of lactose broth cultures or the cultures themselves when taken by human beings orally can produce any symptoms whatever. As many as four billion organisms have been taken of one strain with no appreciable effect. When large numbers are ingested the organism may appear for a day or so in pure culture in the stool but it is quickly displaced by the normal intestinal flora.

Some importance nevertheless may be attached to Pseudomonas. There is evidence that this organism can inhibit or mask the growth of coliforms in mixed cultures, raising the question of

whether the absence of gas in presumptive tests where this organism is found definitely excludes the possibility of coliforms also having been present in the sample.

The failure of the laboratory to find a responsible agent in water implicated, for the reasons outlined in the preceding section, was not wholly without precedent. The conditions which cause water-borne gastro-enteritis have never been satisfactorily demonstrated. Reasons have been given, however, for considering that the condition has an infectious, probably bacterial, basis.

General Observations.

Back-siphonage and cross connection possibilities were explored by Mr. Perkins of the Kentucky State Health Department. There are no local industries active in Georgetown, the local pasteurizing plant and the college being probably the largest users of water in the city. Certain defective installations were uncovered but it was difficult to see how these could account for so wide-spread an outbreak as the one in question.

It seems more likely that what was probably an infection came through the plant from the original source of supply, the Royal Spring.

Reasons have been given, in the report presented shortly after the outbreak, for considering the treatment of water at Georgetown as inadequate. Filtration, and at times chlorination, was shown to be faulty and this is corroborated by the periodic high total counts shown in Table 5.

When fires occur, and there were an unusual number of these during the preceding week,* the water sometimes receives rather hasty treatment owing to lack of adequate water storage in the distribution system. At such times also the flow in the mains is accelerated and sedimented material and bacteria in the mains may be stirred up in considerable numbers.

The possible sources of pollution of the spring were therefore explored at some length.

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* Four fires occurred on the following dates: Wednesday, November 13, at noon; Saturday, November 16 at 5 a.m. with another at noon; Sunday, November 17 at 9 a.m.

The Royal Spring is really the outlet of a small underground river flowing through cavernous limestone formation until it reaches the surface at the bottom of a small limestone cliff near the center of Georgetown. There are several such streams in the vicinity of Georgetown, each draining, usually, the higher ground southward from the outlet. Surface water reaches the underground collecting caverns through "sink-holes" in the bottom of "sinks" -- more or less circular depressions from a few feet to several hundred yards in circumference -- scattered along the course of the underground streams.

The practice prevails of dumping all manner of debris in the "sink-holes" down which surface water drains from these depressions into the underground streams. Such accumulations gradually disappear - even when piled high. There is a small "sink" nearly filled with ashes located within a hundred feet of the spring. On farms further from the city, "sink-holes" are convenient burial places for dead animals. The carcasses of the larger animals are, in general, sold to a rendering plant. Sewage also may be piped off to a "sink-hole" to avoid the necessity of building a cess-pool. Many sink-holes are to be found in pastures south of Georgetown where there are extensive accumulations of animal feces.

Under these conditions it is not hard to see why rains over the collecting surface of the spring vastly - and sometimes with incredible rapidity - increase the bacterial load of the water issuing from the Royal Spring. In the underground caverns there are doubtless sludge deposits and the increased current after rains probably stirs these up much as flushing a hydrant roils a water main.

With conditions such as this constant vigilance by trained operators and faultless equipment for treating water are indicated. These are not available in Georgetown.

Summary.

An explosive epidemic of gastro-enteritis, of short duration, occurred in Georgetown, Kentucky, on November 16, 17 and 18, 1940, following rains that caused increased flow and turbidity of the water from Royal Spring, the source of the city's water supply.

Bacteriological records showed that the effectiveness of water filtration and/or chlorination was quite variable.

The incidence among persons using private well and cistern water for drinking was much lower than in persons using the city supply.

Age and sex distribution of cases in a canvassed population was nearly uniform.

There was a definite incubation period of 36-72 hours, suggesting an infectious, rather than a toxic, etiology.

Very few confirmed coliforms were found in samples taken during this investigation. This might be due to increased chlorination beginning when the outbreak became apparent. It is, however, possible some organisms, not ordinarily detected by standard bacteriological methods, may be the cause of attacks of the type of gastro-enteritis encountered in this outbreak.

Acknowledgment.

Acknowledgment is made of extensive courtesy and assistance on the part of the Kentucky State Health Department, the Scott County Health Department and the officials of the local water plant, also Dr. P. R. Edwards of the University of Kentucky for assistance in determining the identity of certain organisms.

APPENDIX III.

Gastro-enteritis Outbreak in Navarre, Ohio

EPIDEMIOLOGICAL STUDY OF WATER-BORNE GASTRO-ENTERITIS IN NAVARRE, OHIO

By
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On the 23rd of February, 1941, an unusually high prevalence of gastro-enteritis in the village of Navarre, Ohio, was brought to the attention of Dr. Underwood, of the Stark County Board of Health. The County Health Department obtained four water samples from scattered points on the distribution system which, upon bacteriological analysis at the State Health Department laboratory, revealed the presence of coliforms. Examination for coliforms, presumptive and confirmed, were made on two 10 cc. and two 1 cc. portions of each sample. The results of these analyses are shown in Table 1.

TABLE 1

GAS FORMATION, CONFIRMED FOR COLIFORMS, IN FOUR TAP WATER SAMPLES FROM NAVARRE, OHIO FEBRUARY 24, 1941

Sampling Point	Volume of Portion			
	10 cc.	10 cc.	1 cc.	0.1 cc.
High School	+	-	-	-
"Big Wick's Place"	+	-	-	-
Navarre Club	+	+	+	-
Home of D.A.Fisher	+	+	+	-

On the 25th a routine sample was taken independently at the school and showed no coliforms. On March 1st the State Health Department, in cooperation with the Stark County Health Department, made a careful study of the local situation and took duplicate samples from (1) water at the pumping station before the pumps were started, (2) the same after the pumps had been in operation for a considerable period, (3) the Sohio Gas Station, (4) the Herwick Saloon, (5) Reamer's Filling Station, and (6) the High School. Each duplicate sample was examined independently, making twelve samples for this one day. Those from the High School both showed gas confirming for coliforms in one of the two 10 cc. portions - none in the 1 cc. portions. The remaining samples were negative for coliforms.

An emergency hypo-chlorinator was obtained and installed and on March 8 duplicate samples from three points on the distribution system were all negative.

Through the cooperation of the State and County Health Departments the Gastro-enteritis Study Unit of the Ohio River Pollution Survey was permitted to make an extended study of the outbreak, beginning on the 7th of March. A house-to-house canvass of a considerable portion of the village population was first made and then a series of field laboratory and sanitary engineering tests were conducted.

Results of House-to-house Canvass.

The village of Navarre had 1703 inhabitants at the time of the 1940 census. The canvass included 382 persons in 106 households distributed throughout the village. A total of 115 cases occurred in the canvassed population. The incidence of 30 per cent obtained from these figures is low for reasons which will be stated below.

Data on the time of occurrence of cases are somewhat obscure. The canvass was begun on March 7 and the outbreak had occurred fully two weeks before that time, so that dates of onset were not readily obtained, though a calendar was carried by the canvassers to assist the informants when there was doubt. Table 2 gives, however, the best available picture of the distribution of cases in respect to time.

TABLE 2.

DATES OF ONSET OF CASES IN THE CANVASSED POPULATION

Cases	Dates of onset February							
	Prior to Feb. 22	22 Sat.	23 Sun.	24 Mon.	25 Tues.	26 Wed.	27 Thurs.	28 Fri.
Cases with onset on given date	7	20	26	13	8	4	3	2

There were some definite irregularities about the distribution of cases within the village. The Northern, Eastern, and Central portions suffered heavily but the Western and Southern portions had few cases.

The age-incidence shows no striking differences in the various decades. The figures for the canvassed population are given in Table 3. The disorder tended to prevail in the middle decades of life and was considerably less in the younger and older decades.

TABLE 3

AGE-INCIDENCE OF GASTRO-ENTERITIS IN THE CANVASSED POPULATION OF NAVARRE, OHIO

Age	Attacked	Total Canvassed	Percent Attacked
Under 2	2	11	18
2 - 9	14	55	25
10 - 19	21	61	34
20 - 29	21	55	38
30 - 39	20	50	40
40 - 49	15	54	28
50 - 59	12	45	27
60 and over	8	49	16
Unknown	2	2	
All ages	115	382	30

This age-incidence is quite characteristic of both person-to-person contact outbreaks and of water-borne outbreaks. Against the contact hypothesis is the explosiveness and short duration of the outbreak as shown in Table 2. Influenza itself could hardly have reached a peak and declined so rapidly as this outbreak did. More definite, however, than the foregoing indication is the difference between the incidence among persons drinking water from private well supplies and those drinking water supplied by the city. Fifty-one persons were found using private wells of whom only 7, or 13 percent, were attacked. On inquiry it was found that every one of these 7 had habitually used village water while at school or at work. All of the individuals sure of having taken no water from the public supply escaped. Most of these persons had had the same contact opportunities as others living in the village.

Of the 331 canvassed individuals using the village supply habitually, 108 were attacked - an incidence of 33 per cent. Had the canvass been made closer to the time of the outbreak more cases might have been recalled. It was noted that inquiries made in the later days of our investigation showed fewer cases than those made in the earlier days, even in the same parts of the village, suggesting that mild cases had been forgotten. It is probably safe to put the figure for the village as a whole at not far from 40 per cent.

The relative immunity of the Western and Southern sides of the village is not difficult to explain. These are areas of relatively low water use and of correspondingly little flow of water through the mains, the principal flow being rather from the pumping station and storage tank in the Northwest to the dairy and bakery towards the center of town and the Southeast.

No other common factor could be found. Food was bought at various stores. Baked goods were supplied as often by the local bakery as by a delivery wagon selling goods made in a distant city. The incidence was about equal among families on several milk routes.

As in other places where these outbreaks have occurred, many statements were collected during the canvass to the effect that a number of other more or less distant localities had been simultaneously affected, and that persons on private well supplies both in the village and on outlying arms had been attacked. These reports were carefully investigated. In one instance, what appears to have been a typical attack (but was possibly a case of food-poisoning) was found on a farm near the village

limits where the use of village water was denied. In other instances isolated cases were found on the surrounding farms; invariably among children attending the village school. The fact that these cases did not spread to others in the household is further evidence against the hypothesis of spread by person-to-person contact.

These outlying cases are of some epidemiological importance in addition to the assistance they offer in determining the vehicle for the outbreak, for it will often be found that they supply sufficient data for establishing an incubation period. The schedule used in canvassing provides a space for recording visits away from home at the time of the outbreak and visitors to households in Navarre from out of town during the same period. Only two such visitors to a canvassed household in Navarre could be traced; they were a wife and her husband who had come to Navarre from Cuyahoga Falls to visit the wife's family. The two had remained for only an hour; neither eating any food and only the wife drinking water. Two days later the wife was attacked with nausea, cramps and diarrhea. The incubation period of 36 to 72 hours has been noted in other outbreaks and offers a strong clue to the fact that a true infection and not a mysterious "poison" underlies the syndrome of water-borne gastro-enteritis. It was possible to learn of only two attacked persons who left town during the outbreak. Both were school teachers who left Friday evening and were sick immediately on their return Monday morning. The probability is that they had been infected on Friday because the incubation period would otherwise be too short. Their evidence would place the infectious element in the water as late as Friday the 21st.

Laboratory and Sanitary Data

The laboratory evidence indicating that pollution of the water supply had occurred has been presented in the introduction. It remained to determine whether this pollution had occurred at the source of supply or at some point along the distribution system. As the outbreak seemed too widespread to have resulted from a back-siphonage or defective cross connection, attention at first centered on the source of supply.

A detailed report of the sanitary study of the wells and pumping station of Navarre made by Mr. Lathrop on March 1, 1941, is on file in the Sanitary Engineering Division of the Ohio State Health Department. Here it suffices to note that five wells in the Northwest part of the village, from 30 to 40 feet deep and with casings about twenty years old, constituted the

water supply. They form a line parallel with an old canal (now a relatively stagnant lagoon) and about forty feet from it. The remains of the canal tow path lie between the canal and the wells. On the other side of the line of wells and from 50 to 100 feet away flows the Tuscarawas River in a sharp curve. When the wells were first installed they must have been further from the river than at present, but now the current has undercut the bank so that it comes within fifty feet of one of the wells. When the river is in flood the well-heads are submerged; only a two foot rise above the level observed at the time of the survey would have accomplished this. There had been, however, no such flooding of the well-heads for months before the present outbreak.

When uncapped, these wells flow a few inches over the casing - indicating a head of water greater than the river and perhaps greater than that of the nearby canal. Continuous pumping, however, draws the level down 10 or 12 feet.

The pumping station on the line of wells contains an electrically driven pump which sends the water to the main on Wooster Street and into the village grid. An elevated storage tank provides pressure when the pumps are not working and is located on the North edge of the town at the head of Park Street.

Only one of the wells (Number 5) could be tested individually because the valves at the well-heads were considered rusty and unreliable. This well, however, was the one nearest to a badly polluted section of the lagoon and also nearest to the river. Tests were accordingly first made on this one well on March 21. The bacteriological tests consisted of a standard water analysis for coliforms, with detailed attention to the type of growth in the lactose broth tubes. Two supplementary chemical tests were also made - for chlorides and for hydrogen ion concentration. The characteristics of the two potential sources of pollution - the river and the lagoon - with respect to the various tests may be briefly outlined.

The sewage from the city of Massillon and various industrial plant wastes are carried by the river, which therefore was high in coliforms and chlorides but relatively low in pH (7.1). The lagoon showed few coliforms (about 20 per 100 cc.), the chlorides 8.5 p.p.m. and the pH was 7.7. Any coliforms in the wells could come from either source and, as the normal well water customarily ran lower in chlorides than the river or the lagoon, the chlorides should rise with prolonged pumping if pollution were drawn in from either source. The hydrogen ion

concentration of the wells might, however, assist in differentiating. The normal well water ran a pH of 7.3 - 7.4, and a tendency for this to drop or rise under prolonged pumping would indicate pollution from the river or the lagoon, respectively.

The results of the tests on well Number 5 are given in Table 4 under date of March 20. The continued absence not only of coliforms but of any growth whatever in the fermentation tubes, the tendency for the chlorides to drop, and the relative constancy of the pH gave a fairly definite proof of the lack of pollution of the well from either source during the hour and a half test run. Eleven and a half inches of vacuum were carried during this period which was considered excessive for prolonged pumping. This well was, therefore, cut out for the night and allowed to refill. Pumping on it was resumed in the morning for another hour and a half. Two samples were secured from this run - an early and a final one. The results of tests on the second run confirmed the first; they are given in Table 4 under date of March 21.

TABLE 4

TEST OF WELL NO. 5, NAVARRE, OHIO

March 20 and 21, 1941

Date	Time	Total Count per cc.	Coliforms Per 100 cc.	Chlorides p.p.m.	Hydrogen Ion Conc.
March 20	3:30 P.M.	3	0	4.7	7.4
	3:50 P.M.	2	0	4.0	7.4
	4:10 P.M.	1	0	4.0	7.4
	4:25 P.M.	0	0	3.5	7.4
	5:15 P.M.	1	0	3.7	7.4
March 21	9:45 A.M.	0	0	5	7.2
	11:36 A.M.	0	0	-	-
	10:40 A.M.	0	0	4.7	7.3

As the remaining wells could not be tested individually it was decided to make a prolonged pumping test on all the wells and to waste through hydrants at dead ends in order to prevent excessive pressures in the system. An order was issued to boil all drinking water in the village on the morning of the test, a pressure recording gauge was installed in a home near the uppermost part of the system, and the elevated tank filled and cut off to provide water for use in case of fire. The emergency chlorinator was then shut off and the pumps were started at 10 a.m. Hydrants were successively opened until six were flowing at one time. It was found possible to maintain fair pressure in the system under these conditions, but the vacuum at the wells reached 12 inches - the maximum it was felt the wells could take, and at 1:30 p.m. the pumping and wasting were discontinued.

During this period regular samples were taken at the wells for bacteriological and chemical tests as on the test of well Number 5. Samples were also secured of the turbid water shortly after dead end hydrants were opened and also just before they were closed. A pronounced hydrogen sulphide odor was noted in the water at the pump-house and at several of the dead ends toward the close of the test period.

Table 5 shows the results of the various tests at the wells. Table 6 shows the findings for the samples from the dead ends, both initially and at the end of the run.

TABLE 5.

BACTERIOLOGICAL AND CHEMICAL FINDINGS
DURING TEST OF WELLS,
NAVARRE, OHIO
March 25, 1941

Sample No.	Time	M.P.N. Coliforms per 100 cc.	M.P.N. Bacteria per 100 cc.	Slow Lactose Fermenters	Pseudomonas	Chlorides p.p.m.	Hydrogen Ion Conc.
1	10:05 A.M.	0	2.2	0	0	7.5	7.3
2	10:35 A.M.	0	0	0	0	4.0	7.3
3	10:50 A.M.	0	0	0	0	4.0	7.3
4	11:19 A.M.	0	0	0	0	4.2	7.3
5	11:50 A.M.	0	5	0	0	4.0	7.3
6	12:20 P.M.	0	9	0	+	4.0	7.3
7*	12:50 P.M.	0	12	0	+	4.0	7.3
8*	1:20 P.M.	0	39	0	+	4.0	7.3

* Strong odor of hydrogen sulphide in these last samples.

The most striking fact about Table 5 is that an increasing number of bacteria begin to appear after prolonged pumping as shown in the column headed "M.P.N. per 100 cc." from 11:50 a.m. to 1:20 p.m. These bacteria were of two kinds only: One, a Pseudomonas producing a characteristic water-soluble green pigment on certain media and the other an organism as yet unidentified. The latter appears to be only a saprophyte, but the former may conceivably have pathogenic significance. Organisms of the genus Pseudomonas have long been suspected of causing enteric disturbances. However, several detailed studies have been made on them in this laboratory, whole cultures being ingested by volunteers without evident ill effects. Their appearance in water may, however, be of significance from other points of view. It is known that they are very widely distributed in nature and that they are common in sewage. They are more filterable than coliforms and conceivably might be an early index to pollution. Organisms of this genus are known to produce cyanides under certain conditions of growth. Finally, their presence may interfere with the detection of coliform organisms.

These facts would seem to warrant making an effort to rid the supply of these organisms even though their direct pathogenicity cannot be proven. Because they occur, even after prolonged pumping, in small numbers, it is probable that they originate from one well only. This well may also be the source of the hydrogen sulphide odor noted as being particularly strong at the very end of pumping. Because of the difficulty of determining which well is involved, it may be necessary to rely solely upon chlorination of the supply as the most practical way of dealing with these organisms. In this connection, however, it should be noted that the occurrence of hydrogen sulphide is an unfavorable factor where chlorine is used, tending to limit considerably its effectiveness, unless proper allowance is made for absorption of chlorine by the sulphide.

So much for the findings of the study of the source of supply. The results of the study of the distribution system are presented in Table 6. The total count per cc. is seen to have been abnormally high only in the Ohio Street Loop, suggesting some degree of stagnation. Frequent flushing of this loop would seem to be indicated. The index type of coliforms was not encountered in the test at any time. The bacterial M.P.N. was high due to the extensive stirring up of the system. Late lactose fermenters and Pseudomonas were isolated from all but a few of the samples.

TABLE 6

BACTERIOLOGICAL FINDINGS
ON SAMPLES FROM DEAD-ENDS AND HYDRANTS
NAVARRE, OHIO

Sampling Point	Total count per cc.		M.P.N. Coliforms per 100 cc.		M.P.N. Bacteria per 100 cc.		Slow Lactose Fermenters		Pseudomonas	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed
North & Main Sts.	2	0	0	0	Over 110	21	+	+	+	0
N.Market & Corp. Line	1	0	0	0	Over 110	9	+	+	0	+
4th & Columbiana Sts.	1	0	0	0	Over 110	39	0	0	0	+
Columbiana & Canal	2	0	0	0	Over 110	39	+	+	0	+
Tuscarawas & 4th Sts.	0	1	0	0	Over 110	39	+	+	+	0
Tuscarawas & 2nd Sts.	1	0	0	0	Over 110	39	0	+	+	+
Ohio and Main Sts.	50	0	0	0	Over 110	39	+	+	+	0
Ohio & Wilmott Sts.	59	1	0	0	Over 110	15	+	0	+	+
Wooster & E.Corp.Line	0	0	0	0	2.2	39	0	+	0	+
Canal & Main Sts.	1	0	0	0	48	39	+	+	+	0

While no evidence was found of pollution from points inside the water distribution system on this rather drastic test, there are grounds for believing that such pollution actually may have taken place. The coliforms found in the early samples examined by the State Health Department apparently could not have come from the wells, and if they did not they must have come from some point inside the system. The peculiar distribution of cases in the village offers some rather uncertain clues as to the point of entrance. Cases were most numerous (nearly 100 per cent) on the line from the elevated storage tank at the head of Park Street down to Wooster Street and along Wooster Street toward the center of town. The west end of Wooster Street is supplied by the main carrying water from the pumping station to the elevated storage tank and few, if any, bona fide cases occurred on this main. The inference is that pollution occurred at some point on Park Street north of Wooster and that polluted water either filled the tank, whence it was carried throughout the village, or that it was fed into the main close to the base of the tank and so was distributed to the town. With the exception of a plugged sewer connection for a house nearly at the top of the hill on Park Street, no remotely conceivable source for pollution was found at the time these studies were made. However, the distribution of cases makes this a distinct possibility.

The maintenance of a fair chlorine residual in the water at all times would tend to minimize the danger of recurrence if this hypothesis is correct and would also serve to help to remedy the situation noted under the discussion of the bacteria found in the water at the wells. The advisability of safeguarding this supply by continuous and effective chlorination cannot be too strongly recommended.

Periodic sampling of the water at various points throughout the distribution system, including two or three samples from homes near the tank, is also recommended, on the chance that a mild recurrence may be detected.

A pressure recording gauge located either at the pumphouse or at the top of the hill near the storage tank would provide invaluable information about conditions within the system and about the frequency and duration of pump runs. Lack of such data greatly complicates the understanding and prevention of outbreaks like the present one.

Grateful acknowledgment is made of the active cooperation in this study rendered by the Stark County Board of Health and by officers of the State Department of Health.

APPENDIX IV.

Dysentery Outbreak (Shiga) in Adair County, Kentucky

LABORATORY FINDINGS IN AN OUTBREAK OF SHIGA DYSENTERY

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On June 26, 1941, the Kentucky State Health Department requested the services of the mobile laboratory of the Epidemiological Unit of the Ohio River Pollution Survey for the study of an epidemic of diarrhea with an unusually high mortality in Columbia, Adair County, Kentucky. The general epidemiological findings of this outbreak are to be described by Caudill and others elsewhere; the present note will outline some of the advantages of having a well-equipped mobile laboratory for use in epidemiological control of diarrheal disease outbreaks in areas remote from centers with laboratory facilities and will give certain basic laboratory findings in detail.

The mobile laboratory used in the study here described was housed in an 18-foot trailer towed by a coupe. Electricity for lights, hot plate, incubator, oven, and serological bath was provided through an electric cable with sharp pointed spring clamps for attachment to any electric service wires carrying sufficient amperage and voltage. Water was obtained by a hundred foot hose attachable to any faucet. Tanked gas was carried for the autoclave and for Bunsen burners. When the trailer was located, the tow car could be unhitched and driven independently for the purpose of distributing specimen containers and bringing specimens back to the laboratory.

This unit was based at Cincinnati, Ohio, some two hundred miles north of Columbia. On the day that the request for the laboratory was received a stock of MacConkey's and of Krumwiede's triple sugar agar was made up and other media of possible value in the isolation of organisms of the Eberthella, Shigella and Salmonella groups from stools were stocked on the trailer in dehydrated form.

The laboratory left Cincinnati at 7:30 a.m. on June 27, arrived in Columbia at 3:30 p.m. and was located and set up, ready for operation, by 4:00 p.m. of the same day.

The choice of media was not a hard one to make when a few cases had been reviewed hastily. Patients were of all ages

and appeared to be toxic, stools were passed frequently and consisted of limited amounts of tenacious pus and mucus, or of blood-streaked creamy pus and mucus. MacConkey's agar and Shigella-Salmonella agar (Difco) plates were poured and prepared for streaking. All plates were cooled under wet towels in a stream of air from an electric fan.

Meantime, stool specimen outfits were left with a number of patients. Each outfit consisted of paper plates, paper spoons and sterile metal containers without preservative. The patients were instructed to defecate on the plate and transfer the specimen to the container by means of the spoon. Plates were left in the homes upside-down on a table and covering the spoons so that flies could not contaminate them. Where freshly removed diapers were available, these were taken to the laboratory direct, without using the containers.

By 8:00 p.m. - four hours after the trailer was installed - the plates had dehydrated sufficiently for use and eighteen stool specimens had been secured. These were inoculated in duplicate, both on MacConkey's and on Shigella-Salmonella agar and were incubated at 37°C. By noon of the following day a fair growth of colonies, suspicious in appearance, was present on many of the plates. Presumptive agglutinations were made directly from the colonies on the plates with 1/20 dilutions of the following diagnostic rabbit antisera: Shiga, Polyvalent dysentery and Flexner. The majority of the colonies selected gave good agglutination with the first two, but none with the last antiserum. Suspicious colonies were also fished to Krumwiede's triple sugar agar slants and positives subsequently were purified and carried through the various cultural and serological reactions necessary for identification.

One of the outstanding advantages of the use of mobile laboratories in the control of epidemics like the one described here is that quick and efficient laboratory diagnosis is supplied. Although further stools were examined upon which more comprehensive data will be presented below, it may be of interest to outline briefly the final results of the analysis of the first eighteen stool specimens to illustrate this point.

When carried through triple sugar, sugar fermentation, and serological reactions, twelve of the eighteen stool specimens were found to be positive for Shiga dysentery. The eighteen specimens had been secured from fourteen patients (some patients having supplied more than one stool) and the number of patients represented by the twelve positive specimens was eight. The six negative sets of plates were from the stools

of five patients all of whom were in the second or third week of their illness; one set of plates was overgrown and could not be studied further.

Having completed the first, or diagnostic phase of the work the mobile laboratory was brought back to Cincinnati, on June 30, for administrative reasons. On July 21, the trailer was returned to Columbia where it remained until August 8. In the interval the epidemic in Columbia proper had begun to subside, but small rural foci of dysentery had developed, some of which were small unrelated outbreaks perhaps of Flexner and paradysentery, others of which were clearly related to the urban focus of Shiga. The aid of the Red Cross had been invoked and a small hospital for dysentery patients had been set up. Also, the question of the advisability of a convalescent carrier study had been raised. The second visit of the mobile laboratory had, therefore, not only a case diagnostic, but also a carrier, study function to perform.

As the laboratory was not present throughout the period of the epidemic, it will be evident that the cases diagnosed definitely by stool analysis represented only a limited number of the total cases which occurred during the whole period of the outbreak, including no cases for the period of June 30 to July 21, inclusive. Some attempt was made to bridge this gap by securing blood samples for agglutination from persons who recovered, were in the third or fourth weeks from the onset of their illness, and whohad not been otherwise studied during the acute phases of the attack. Because the carrier study was added to the diagnostic study during the second visit the total number of positive isolations became only a limited fraction of the total number of stool examinations made.

Before presenting the results of the analyses it may be useful to detail the procedure adopted in order to convey some idea of the scope of the work which it is possible to carry out in a well-equipped mobile laboratory. During the second visit of the trailer an assortment of sugar media was stocked to permit cultural study and complete equipment for serological study was also included. The following routine was then adopted: When a stool specimen was brought in it was streaked on duplicate plates of MacConkey's and Shigella-Salmonella agar and in several instances a microscopic examination of the stool was made, the presence or absence of mucus, pus or blood cells being noted.*

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* These microscopic checks were found to be unexpectedly useful because on certain days stools of many convalescents at the hospital were noted grossly to be flecked with red causing some consternation among the attendants. Microscopically, no blood cells could be seen, and the red flecks were identified as fragments of stewed tomatoes served on the previous day.

After 18 to 24 hours incubation at 37°C. the stool specimen plates were examined and suspicious colonies were fished to Krumwiede's triple sugar agar slants. After 24 hours incubation at 37°C. the Krumwiede's slants were read and those with typical Eberthella-Shigella reactions* were subjected to presumptive agglutination and were purified. Purified cultures were transferred to nutrient agar slants to develop growth for antigen for final serological confirmation and were inoculated into mannitol, Glucose, sucrose, lactose, maltose, rhamnose and tryptone broths (the latter for indole testing). In the fourth 24 hour period the first readings were made on the reactions in the sugar media and final agglutination tests were made. Dilutions of Shiga, Polyvalent dysentery and Flexner rabbit antisera up to 1/3600 were prepared for this purpose. Thus by the fifth day a definite conclusion as to the nature of the organism was obtained.

A total of 211 stool specimens were collected from 94 patients. Forty-six of the specimens from 27 patients were found to be positive for dysentery and dysentery-like organisms. A great many of these cases were examined because of the occurrence of diarrhea even though there was no history of contact with, or proximity to, cases or foci of known Shiga dysentery. There were 132 stools from patients whose relationship, familial or geographic, with known Shiga patients led to a strong suspicion that they were Shiga cases. Of these 31 were positive for Shiga dysentery. The 132 specimens were supplied by 49 patients and the 31 positive specimens represented a total of 17 diagnosed cases of Shiga dysentery. The remaining positive cultures, which were from cases of dysentery, Shiga (2 cases), Sonne (4 cases), Hiss (2 cases), Flexner (1 case) and typhoid fever, E.typhosa (1 case) will be discussed when the cultural and serological characteristics of the organisms are presented.

The low ratio of positive specimens to total examinations was due in part to the fact that a large number of examinations for carriers was made. A better measure of total effectiveness in diagnosis will be given below when the results of the analysis of stools of this group are presented according to the duration of the disease.

As nearly all stool examinations were made in duplicate on MacConkey's agar and on Shigella-Salmonella agar it may be useful to compare the results obtained by the use of the two.

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* Acid butt, without gas and no change in slant.

Table 1

Comparison of MacConkey's Agar and Shigella-Salmonella Agar for the Isolation of Organisms of the Shigella Group from Stools.

Findings on duplicate plates of MacConkey's and Shigella-Salmonella Agar	Number of Stool Specimens
Both plates positive	25
Both plates negative	155
MacC. positive, S.S. negative	3
MacC. negative, S.S. positive	21
Comparison not possible	7
	211

These results are shown in Table 1 where, of 204 examinations in which a comparison is possible, MacConkey's agar gave positives in 28 examinations, and Shigella-Salmonella agar in a considerably higher number - 46. Because of the large number of negative examinations made necessary by the carrier study the total percentages of success with either medium are low; a fairer basis might well be the total proportion of each which was positive with either medium or both. By this measure it will be seen that Shigella-Salmonella agar gave 46 out of the total 49 positive, while MacConkey's agar gave only 28.

In actual practice, the advantage from the use of Shigella-Salmonella agar in trailer laboratories is considerably greater than would appear from abstract figures for the following reasons:

1. It is more readily available for use than MacConkey's because it does not have to be autoclaved before use.

2. Plates may be directly streaked with fairly heavy inocula without dilution or other precautions against overgrowth and only one plate need be used for each stool.

3. The number of suspicious colonies tends to be greater and coliform colonies fewer, giving a far better selection.

The extent to which positive stool findings could be made with either medium singly at varying intervals after the onset of diarrhea is shown in Table 2. Here, as in previous discussions of results, the data are given for all findings and then for cases presumed to have been Shiga dysentery on the basis of contact with previous cases or foci of infection.

Table 2

Number of Stools Examined at Specified Intervals After Onset of the Disease and Number and Percent Positive on MacConkey's and on Shigella-Salmonella Agars.

Interval in Days (incl.)	Total number of Stools Examined	Positive MacConkey	Positive S.S.Agar	Percent Positive MacConkey	Percent Positive S.S.Agar
		(A) All Specimens			
0 - 3	37 (1)	10	17	28	46
4 - 7	35	12	19	34	54
8 - 15	51 (1)	5	10	10	20
16 - 60	70 (1)	0	0	--	--
	193	27	46	14	24
		(B) Specimens from Shiga Contacts			
0 - 3	22 (1)	8	12	38	57
4 - 7	18	7	8	39	44
8 - 15	31 (1)	4	6	13	19
16 - 60	64 (1)	0	0	0	0
	135	19	26	14	19

(1) One stool in each of these intervals is not examined on MacConkey's Agar.

The percentages for positives on Shigella-Salmonella Agar in Table 2, it will be noted, are but little higher than those for MacConkey's, but they tend to be consistently higher in the three groups where positives were obtained. Table 2 also shows that by the end of the second week very few stools were found to be positive and that a sizable group of examinations for the third and succeeding weeks (16-60 days) gave no positives at all. These seventy examinations, however, represent stool studies on only 27 patients. If the carrier rate for Shiga dysentery is actually in the neighborhood of 3 per cent* it could easily happen that this number of patients might have been examined without finding one positive. The results of the

* Kolmer, J.A. and Taft, L. "Clinical Immunology, Biotherapy and Chemotherapy, 1st ed., p.568. W.B.Saunders & Co., 1941.

somewhat limited number of microscopical examinations are briefly presented. A great many of the stools received from patients early in the disease showed mucus, pus and blood upon gross examination. The same findings, of course, were evident on microscopical examination with significant exceptions heretofore mentioned. Where mucus, pus and blood were in evidence, the stool was commonly found to be positive on bacteriological examination. The comparative findings are shown in Table 3.

Table 3

Microscopical and Bacteriological Findings in Stools of 35 Patients Where Microscopical Examination was Done.

Microscopical Findings	Total with Specified Microscopical Findings	Positive Bacteriologically for Dysentery
Negative for mucus, pus and blood	17	2(1)
Mucus and pus only	4	2
Mucus, pus and blood	14	12
	35(2)	18

(1) One of these, a fatal case in an infant, was negative on microscopical and positive for Shiga dysentery. The other was a para-dysentery case.

(2) Eight stools showed parasitic ova, as follows: ascaris - 4; enterobius - 3, dog tapeworm - 1.

The cultural, biochemical and serological characteristics obtained on the organisms isolated are presented in Tables 4 and 5. On the basis of the consensus of the characteristics determined the first 19 cultures in order in these tables are judged to be Shiga strains, the next 4 are considered Sonne types, the next 2 Hiss Y, and the last 2 Flexner and E.typhosa respectively.

(Insert Tables 4 and 5)

Table 4

Cultural Characteristics of Organisms Isolated

Culture No.	Krumwiede Triple Sugar Slants		Motile	Indole	Action on Carbohydrates				Alcohols	
	Slant	Butt			Glucose	Lactose	Sucrose	Maltose	Mannitol	Rhamnose
1	NC	A	-	-	A	-	-	-	-	-
2	NC	A	-	-	A	-	-	-	-	-
4	NC	A	-	-	A	-	-	-	-	-
6	NC	A	-	-	A	-	-	-	-	-
9	NC	A	-	-	A	-	-	-	-	-
10	NC	A	-	-	A	-	-	-	-	-
11	NC	A	-	-	A	-	-	-	-	-
13	NC	A	-	-	A	-	-	-	-	-
14	NC	A	-	-	A	-	-	-	-	-
15	NC	A	-	-	A	-	-	-	-	-
19	NC	A	-	-	A	-	-	-	-	-
20	NC	A	-	-	A	-	-	-	-	-
22	NC	A	-	Tr.	A	-	-	-	-	-
23	NC	A	-	-	A	-	-	-	-	-
25	NC	A	-	-	A	-	-	-	-	-
26	NC	A	-	-	A	-	-	-	-	-
27	NC	A	-	-	A	-	-	-	-	-
29	NC	A	-	-	A	-	-	-	-	-
12	NC	A	-	Tr.	A	-	-	A	A	A
16	NC	A	-	-	A	-	-	A	A	A
17	NC	A	-	-	A	-	-	-	A	A
28	NC	A	-	-	A	-	-	-	A	A
7	NC	A	-	Tr.	A	-	-	-	A	-
18	NC	A	-	Tr.	A	-	-	A	A	-
3	NC	A	-	+	A	-	A	-	A	-
24	NC	A	+	-	A	-	-	A	A	-

Table 5

Serological Characteristics of Organisms Isolated.
Agglutination of Antigens by Following Rabbit Antisera

Antigen No.	Anti-dysenteric Sera					Eberthella typhosa
	Polyvalent	Shiga	Flexner	Sonne	Hiss	
1		1280				
2		1280				
4	1280	1280	-	-	40	
6		1280				
9		1280				
10		1280				
11		1280				
13		1280				
14		1280				
15		1280				
19	1280	1280	-	-	-	
20		1280				
22		1280				
23		1280				
25		1280				
26		1280				
27		1280				
29		1280				
12	-	-	-	640	-	
16	-	-	-	640	-	
17	-	-	-	640	-	
28	40	-	-	1280	-	
7	640	-	160	-	1280	
18	320	-	-	-	320	
3	640	-	640	-	320	
24	80	-	-	-	160	5120

Note the dilutions given indicate the highest titre in which at least a 3+ or better agglutination was obtained. All antigens were made up to a standard density and the full titre of the respective antisera for their homologous antigens was: Shiga, 1-1280; Flexner, 1-640; Sonne, 1-1280; Hiss, 1-1280; E.typhosa, 1-5000.

Certain deviations in the characteristics found for the organisms thus listed, from the usual descriptions given in the literature, should be noted. While indole production was not shown by any of the cultures when the test was made by the Ehrlich-Böhme procedure, faint traces (more definite with 7 and 18) of indole were produced by cultures 7, 12, 18 and 22, when tested by the more sensitive method of Gore. According to available descriptions indole is not produced by the Shiga, Sonne and Ambigua members of the dysentery group, nor by E. typhosa, but is produced by the Hiss, Flexner, Strong and Dispar dysentery strains. With the exception of culture 22, which shows a trace of indole produced, all of the cultures considered to be Shiga types, present a very clear-cut picture.

In the instance of the four cultures listed as Sonne types, the serological results definitely support this decision but all four cultures failed to ferment lactose or sucrose with acid production and two of them, 17 and 28, likewise, failed to ferment maltose. Similarly, cultures 7 and 18 are definitely Hiss strains serologically, but strain 18 ferments maltose with acid production.

In general, however, it is thought that the classifications made here are correct and that the clear-cut serological evidence outweighs the minor discrepancies noted in the sugar fermentations. This is supported by the knowledge that the established criteria for this group are not exact. It is only in the case of culture 3, tentatively identified as a Flexner type, that some doubt exists. Its failure to ferment maltose and its agglutination to a fair titre, 1-320, with Hiss antisera suggests a close relationship to the Hiss strain. However, this culture 3 ferments sucrose and the typical Hiss strain does not.

In passing it might be noted that the polyvalent antiserum used by us was remarkably lacking in Sonne antibodies.

An attempt was made to get blood samples for agglutination tests from individuals who were in the third or fourth week from the onset of their dysenteric infection. For various reasons it was found to be difficult to obtain these specimens. Moreover, the quantity of blood secured in each instance was usually small. As a result only 24 specimens of patients' sera were available for study and the volume of each serum was such that they could be tested against not more than four antigens. A representative Shiga strain from the current study (Adair Shiga) and stock dysentery cultures of Shiga, Flexner and Sonne types were selected for use as antigens. Three of the blood specimens obtained, Nos. 2, 13 and 23, were from patients

whose stools had been cultured and from which typical Shiga cultures had been isolated. (See cultures Nos. 2, 13 and 23 in Tables 4 and 5). The remaining blood specimens were from individuals who had suffered from dysentery during the current epidemic but no bacteriological examinations had been made of their stools. The results obtained from the study of these patients' sera are presented in Table 6.

Table 6

Results of Agglutination Tests with Patients' Sera* set up against Antigens of Known Species and of a Representative Adair County Shiga Strain

Patient Serum No.	Titre** of Patients' Sera Against Antigens for			
	Stock Shiga	Adair Shiga	Stock y-Flexner	Stock Sonne
2	160	320	320	-
13	-	-	160	-
23	20	20	-	-
30	80	80	320	-
31	80	80	40	-
32	-	-	40	0
33	-	20	-	-
34	-	-	-	-
35	-	-	40	-
36	-	-	-	-
37	-	-	320	-
38	-	-	320	-
39	160	320	160	-
40	40	80	320	-
41	20	20	640	-
42	-	-	320	-
43	-	-	-	-
44	-	-	160	-
45	-	-	80	-
46	-	-	20	-
47	-	-	-	-
48	-	1280	320	-
49	640	20	-	-
50	-	-	-	-

* Patients' sera Nos. 2, 13 and 23 were from cases yielding cultures of the same numbers as shown in Tables 4 and 5. All other sera are from uncultured cases.

** Titres recorded here represent a 2+ or better agglutination as set forth on page 235 of Diagnostic Procedures and Reagents, First Edition, 1941, A.P.H.A.

In determining significant titres for agglutination tests consideration must be given to the strength of the antisera used and to agglutinability of the antigens subjected to their action. In obtaining the results of Table 5 fairly potent antisera were used and it is thought that agglutinations below a dilution of 1-320 of the antisera should not be considered significant. With patients' sera, such as those used in obtaining the results shown in Table 6, much lower titres are to be anticipated. Considered from the standpoint of the antigens used the Shiga strain is distinctive serologically while the other members of the dysentery group, particularly the Flexner types, tend toward group, and to some extent auto, agglutination Consequently, it is believed that with patients' sera titres of 1-40 or over against Shiga strains should be considered significant and with the other varieties of dysentery bacteria titres of at least 1-80 and possibly 1-160, should be required.

With these titres as a criterion, it is noted from Table 6 that six patients' sera, Nos. 2, 30, 31, 39, 40 and 49, gave agglutinations to significant titres of 1-40 or higher with the antigen of the stock Shiga culture and six sera, Nos. 2, 30, 31, 39, 40 and 48 yielded significant titres of 1-40 or over with the Adair County Shiga antigen. The failure of serum 48 to agglutinate the stock Shiga antigen while it agglutinated the Adair strain in high titre, and the agglutination by serum 49 of the stock Shiga antigen in high titre while it failed to affect the Adair Shiga antigen above a titre of 1-20 is most unusual. These tests with sera 48 and 49 were repeated twice with identical results. A remarkable specificity in the case of these two sera is indicated. Similarly, the unusually high titres for patients' sera, 1-640 and 1-1280, suggest a marked antibody production for a specific organism. Thus the agglutination of Shiga antigens in significant titres of 1-40 or over by 7 of 24 patients' sera studied is definite evidence, and confirms the observation, that a considerable portion of the dysentery cases in this epidemic were Shiga infections.

No agglutinations of Sonne antigen were observed with any of the 24 patients' sera, even in the 1-20 dilution, although this antigen agglutinated to the full titre of the diagnostic Sonne antiserum used as a control.

Twelve of the 24 patients' sera, namely Nos. 2, 13, 30, 37, 38, 39, 40, 41, 42, 44, 45 and 48, agglutinated Flexner antigen to significant titres. As the bacteriological findings obtained in this study disclosed only one possible Flexner strain this would definitely suggest a very high incidence of endemic Flexner dysentery in this locality with a Shiga infestation superimposed in the present epidemic.

SUMMARY

Using the facilities of a well equipped trailer laboratory a bacteriological study was made of a dysentery epidemic. The marked value of such a mobile laboratory for use at the site of an epidemic is demonstrated.

In this study 211 stools from active cases of dysentery and from convalescents (some as removed as 60 days from onset of infection) were examined.

From these 211 stools representing 94 patients bacteriological diagnosis was made of 27 cases; 19 Shiga, 4 Sonne, 2 Hiss, 1 Flexner, and 1 Typhoid fever.

A brief characterization of the organisms isolated is presented.

A serological study of 24 patients' sera indicates that the current epidemic was a Shiga infection and that dysentery of the Flexner type is endemic in this territory.

Acknowledgments

It is desired to express our indebtedness to various officials of the Kentucky State Department of Health for their co-operation and assistance; also to the various departments of the City of Columbia, particularly the Water Department; and especially to Dr. J. T. Duncan, County Health Officer of Adair County for his cordial and effective co-operation during the time we were making this investigation: and to the medical and nursing staff of the temporary Red Cross hospital that was established at Columbia during the outbreak.

APPENDIX V.

Outbreaks of Gastro-enteritis Traced to Water Supplies

Appendix V
Outbreaks of Gastro-enteritis traced to water supplies.

Locality	First cases noted				Dura. of Epid. (Days)	First Water Samples Taken			Coliforms in early samples	Source of Water Supply	Population		Percent Attacked	REMARKS
	Day of			Day of month		Month	Day	Days from start			Exposed	Attacked		
	Year	Week	Month											
				Source of, and bacteriological evidence for, pollution not found										
Georgetown, Ky.	1940	Fri.	Nov.	15	5	Nov.	18	3	0	Spring	4,500	2,250	50	Unusual no. fires; turbid spring
Cohasset, Mass.	1931	Sun.	Mar.	15	4	Mar.	18	3	0	Wells	3,000	1,000	33	Active flushing of hydrants just before.
Coshocton, O.	1936	Tues.	Feb.	18	N.S.	Feb.	20	2	0	Well	11,000	1,500	17	Freezing & thawing, flooding.
Milwaukee, Wisc.	1938	Mon.	Feb.	7	21+	Daily		0	0	Lake	600,000	- -	11	Sewage blown toward water intake.
				Source of, or bacteriological evidence for, pollution found										
"Indiana Town"	1940	Thurs.	Feb.	1	N.S.	--	--	--	?	River	7,700	- -	26	New filters installed; turbid water in mains.
Navarre, Ohio	1941	Sat.	Feb.	22	3	Feb.	24	2	+	Wells	1,700	680	40	Active flushing of hydrants just before.
Springfield, Mo.	1936		July	16-17	N.S.	July	13-23	0	+	Impounded Spring Well	65,000	20-35,000		Source not described.
"Tennessee Town"	1936	Week ends	June-Aug.	Recurrent	Brief	--	--	--	?	Spring	2,500	765	31	Leak from sewer above spring.
Dallas, Texas	1937		Apr.	8	6	N.S.	N.S.	--	+	Wells	10,000	3,000	30	Source not found.
Altamount, N. Y.	1937	Mon.	May	17	13	N.S.	N.S.	--	+	Surface	900	190	20	Source not found.
Vinton, Iowa	1938	Wed.	Feb.	2	6-7	Feb.	7	5	+	Wells	3,400	2,000	59	Possible pollution of wells.
			Outbreaks with sewage pollution found and followed by typhoid fever cases											
Excursion Steamer	1912		July	29	2-3	--	--	--	N.S.	River	1,200	600	50	Water pumped while steamer over sewer.
Santa Anna, Cal.	1924		Jan.	1	N.S.	--	--	--	+		27,000	10,000	37	Plugged sewer flooding water.
Detroit, Mich.	1926		Feb.	25	N.S.	Daily		0	+	River	1,300,000	45,000		Sewage blown toward water intake.
Greater Rostow, U.S.S.R.	1926		Apr.		14-21	Apr.	24	?	+	River	260,000	40,000	15	Leak from sewer above spring.
Chicago Stock Yd. fire	1934		May	19	--	--	--	--	N.S.	Lake	?	300		Cross connection with polluted supply.
Rochester, N. Y.	1940	Thurs.	Dec.	12	4	Dec.	12	0	+	River	280,000	40,000	9	" " " "

Note: N.S. = Not stated.

APPENDIX VI.

D & E Mortality Statistics for 144 Cities of the Ohio River Basin

Diarrhea and Enteritis Mortality Statistics and
Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Decatur, Ala.	15,983	52.5	48.3	568	34.7	South	Surface
Florence	12,329	60.2	57.2	496	34.7	"	"
Huntsville	12,366	59.9	56.3	628	34.8	"	Ground
Cairo, Ill.	12,696	27.2	23.1	311	37.0	N.W.	Surface
Champaign	22,588	8.3	8.5	738	40.1	"	Ground
Danville	38,259	21.7	16.1	601	40.1	"	Surface
Harrisburg	11,531	52.0	58.8	368	37.7	"	"
Mattoon	15,170	18.4	17.7	739	39.5	"	Mixed
Urbana	14,471	17.8	15.1	725	40.1	"	Ground
Anderson, Ind.	44,826	19.2	18.4	873	40.0	"	Mixed
Bedford	13,862	30.5	29.6	697	38.9	"	Surface
Bloomington	21,544	19.7	20.7	748	39.1	"	Mixed
Connersville	12,842	18.7	19.3	836	39.6	"	Ground
Crawfordsville	10,466	18.6	16.9	757	40.0	"	"
Elwood	11,130	46.3	46.3	860	40.2	"	"
Evansville	110,744	22.1	20.3	374	37.9	"	Surface
Frankfort	12,500	17.1	16.9	854	40.2	"	Ground
Huntington	13,130	22.0	22.9	742	40.8	"	"
Indianapolis	389,148	19.9	18.7	765	39.7	"	Mixed
Jeffersonville	12,874	39.3	43.2	448	38.2	"	Ground
Kokomo	34,234	22.2	22.4	814	40.4	"	"
Lafayette	28,119	23.9	17.9	600	40.4	"	"
Logansport	16,945	8.2	7.5	606	40.7	"	Surface
Marion	24,875	25.7	25.2	813	40.5	"	Ground

Diarrhea and Enteritis Mortality Statistics and
Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Muncie, Ind.	51,562	25.4	23.6	942	40.1	N.W.	Mixed
New Albany, Ind.	27,236	21.1	31.9	413	38.3	"	Surface
Newcastle	13,811	21.1	36.3	1,031	39.9	"	Ground
Peru	12,890	7.9	11.8	642	40.7	"	"
Shelbyville	10,667	16.9	24.3	768	39.5	"	"
Terre Haute	61,172	20.7	30.4	485	39.4	"	Surface
Vincennes	17,768	41.5	62.3	427	38.6	"	"
Ashland, Ky.	36,249	54.6	50.2	511	38.4	South	"
Bowling Green	13,448	62.6	65.1	499	37.0	"	"
Covington	69,318	23.8	21.7	513	39.0	"	"
Fort Thomas	9,958	0.0	----	852	39.1	"	"
Frankfort	11,547	32.9	33.9	560	38.2	"	"
Henderson	11,417	66.3	64.3	374	37.8	"	"
Hopkinsville	11,266	69.2	76.8	556	36.9	"	"
Lexington	47,838	43.2	39.7	967	38.0	"	"
Louisville	344,174	20.7	19.9	459	38.2	"	"
Middlesborough	10,896	110.0	91.3	1,066	36.6	"	"
Newport	29,961	6.6	9.9	506	39.1	"	"
Owensboro	25,436	49.6	48.1	403	37.7	"	Ground
Paducah	37,947	55.6	54.5	344	37.0	"	Surface
Jamestown, N. Y.	48,278	8.6	6.9	1,322	42.0	N.E.	Ground
Olean	22,434	16.6	13.8	1,435	42.0	"	Surface
Asheville, N. C.	61,042	29.2	24.2	2,115	35.5	South	"
Alliance, Ohio	23,771	9.5	9.0	1,079	40.9	N.E.	Mixed

Diarrhea and Enteritis Mortality Statistics and
Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Ashland, Ohio	11,894	6.8	6.3	1,077	40.9	N.E.	Surface
Barberton	26,497	10.1	10.1	965	41.0	"	"
Bellaire	12,458	13.2	12.1	677	39.9	"	"
Bucyrus	9,829	14.1	12.1	1,004	40.7	"	"
Cambridge	17,644	14.1	11.7	801	40.0	"	"
Campbell	16,394	7.0	12.0	772	41.0	"	"
Canton	113,816	6.0	5.5	1,050	40.7	"	Ground
Chillicothe	19,599	10.5	10.3	632	39.3	"	"
Cincinnati	476,118	21.3	19.4	554	39.1	N.W.	Surface
Columbus	317,332	15.6	13.7	766	39.9	N.E.	"
Coshocton	10,939	17.8	16.6	770	40.2	"	Ground
Dayton	225,199	14.5	13.5	764	39.7	N.W.	"
E. Liverpool	24,292	13.8	12.0	686	40.5	N.E.	Surface
Hamilton	57,427	23.4	20.1	598	39.3	N.W.	Ground
Ironton	17,930	48.1	43.3	515	38.5	N.E.	Surface
Lancaster	20,721	18.0	15.7	898	39.7	"	Ground
Mansfield	36,376	8.5	7.7	1,152	40.7	"	"
Marietta	13,865	19.4	16.3	624	39.4	"	Surface
Marion	32,682	16.2	15.4	908	40.5	"	Ground
Martins Ferry	15,969	26.3	18.9	654	40.0	"	"
Massillon	30,877	8.3	7.6	986	40.7	"	"
Middletown	33,190	41.8	37.2	664	39.5	N.W.	"
Newark	32,539	14.9	13.7	822	40.0	N.E.	Surface
New Philadelphia	13,192	6.5	8.0	889	40.4	"	Ground

Diarrhea and Enteritis Mortality Statistics and
Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Niles, Ohio	17,933	11.1	17.1	887	41.1	N.E.	Ground
Norwood	37,636	1.8	2.8	624	39.1	N.W.	Mixed
Piqua	16,494	12.5	11.4	882	40.1	"	Surface
Portsmouth	47,339	65.1	53.4	497	38.7	N.E.	"
Salem	10,784	10.3	7.0	1,207	40.8	"	Ground
Springfield	72,692	9.7	9.4	983	39.9	N.W.	Surface
Steubenville	38,881	18.6	14.7	711	40.3	N.E.	"
Struthers	11,521	10.5	15.3	834	41.1	"	"
Warren	48,069	6.7	5.2	889	41.2	"	"
Wooster	11,140	12.5	12.0	910	40.8	"	Ground
Xenia	10,713	22.4	24.0	917	39.7	N.W.	"
Youngstown	188,726	9.8	8.8	851	41.0	N.E.	Surface
Zanesville	39,876	19.5	16.2	699	39.9	"	Ground
Aliquippa, Pa.	32,961	10.3	16.0	751	40.6	"	"
Ambridge	23,979	8.1	12.6	750	40.5	"	"
Arnold	10,738	7.4	10.0	786	40.6	"	Surface
Beaver Falls	19,322	11.7	10.9	766	40.7	"	"
Bellevue	10,347	9.7	8.3	727	40.5	"	Ground
Braddock	18,554	13.8	11.0	782	40.3	"	Surface
Bradford	21,197	11.9	11.1	1,437	41.9	"	Mixed
Butler	23,463	8.3	9.9	1,011	40.8	"	Surface
Cannonsburg	13,524	4.8	4.1	933	40.2	"	"
Carnegie	12,988	8.0	11.4	769	40.4	"	"
Charleroi	10,982	0.0	----	764	40.1	"	"

Diarrhea and Enteritis Mortality Statistics and Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Clairton, Pa.	15,817	10.2	14.9	1,020	40.3	N.E.	Surface
Connellsville	13,031	19.4	15.9	882	40.0	"	"
Coraopolis	10,922	7.3	12.0	720	40.5	"	Ground
Donora	13,789	2.9	4.5	900	40.1	"	Surface
Dormont, Pa.	13,018	1.5	2.1	750	40.3	N.E.	Surface
DuBois	10,549	13.5	10.9	1,399	41.1	"	"
Duquesne	22,591	8.6	13.3	850	40.4	"	Ground
Ellwood City	12,317	13.0	12.0	894	40.9	"	Surface
Farrell	13,742	8.7	13.5	940	41.1	"	"
Franklin	10,075	8.0	9.4	1,000	41.4	"	Mixed
Greensburg	17,248	16.8	12.1	1,100	40.4	"	Surface
Homestead	19,985	12.3	12.9	756	40.3	"	"
Jeannette	17,375	3.8	5.1	1,000	40.3	"	"
Johnstown	66,824	12.0	9.6	1,176	40.3	"	"
Latrobe	10,866	14.7	11.3	1,008	40.3	"	"
McKeesport	58,558	16.3	13.2	752	40.3	"	"
McKees Rocks	18,819	3.4	6.3	725	40.4	"	Ground
Meadville	17,763	12.7	10.3	1,078	41.6	"	"
Monessen	21,317	10.9	13.6	762	40.1	"	Surface
Munhall	13,364	6.0	7.5	754	40.4	"	"
New Castle	50,545	10.4	9.5	806	41.0	"	"
New Kensington	19,152	14.9	12.7	775	40.5	"	"
North Braddock	17,711	4.9	6.6	1,000	40.4	"	"
Oil City	22,476	7.5	6.6	1,027	41.4	"	Ground

Diarrhea and Enteritis Mortality Statistics and
Related Data for 144 Cities in the Ohio River Basin

City and State	Pop. 1935 (est.)	D. & E. Death Rates per 100,000:1933-37 Mean	Corrected for Residence	Altitude feet above sea level	Lat. North	Region	Source of water supply
Pittsburgh, Pa.	702,556	8.3	7.2	726	40.4	N.E.	Surface
Sharon	25,614	12.5	10.3	854	41.2	"	"
Swissvale	18,590	5.0	7.6	922	40.4	"	"
Turtle Creek	10,295	3.9	6.7	750	40.4	"	"
Uniontown	21,471	29.8	20.6	1,017	39.9	"	"
Vandergrift	11,089	10.8	15.4	800	40.6	"	Mixed
Warren	15,159	12.1	10.4	1,168	41.8	"	"
Washington	26,080	26.8	21.7	1,039	40.1	"	Surface
Wilkinsburg	32,260	4.1	3.7	922	40.4	"	"
Bristol, Tenn.	13,004	26.1	28.4	1,689	36.6	South	"
Chattanooga	150,751	35.7	32.1	660	35.0	"	"
Johnson City	30,935	25.4	16.0	1,631	36.2	"	Ground
Kingsport	13,156	21.1	16.5	1,270	36.6	"	Surface
Knoxville	119,796	37.8	32.9	905	35.9	"	"
Nashville	171,630	36.7	33.0	498	36.1	"	"
Bluefield, W. Va.	21,371	64.8	40.8	2,560	37.2	"	Ground
Charleston	70,808	84.1	58.9	600	38.3	"	Surface
Clarksburg	29,368	17.6	14.3	1,034	39.2	"	"
Fairmont	25,817	31.2	25.3	886	39.4	"	"
Huntington	88,272	36.6	30.4	565	38.4	"	"
Morgantown	18,220	27.6	28.4	892	39.7	"	Mixed
Moundsville	16,283	7.0	8.9	630	37.4	"	Ground
Parkersburg	34,411	38.8	30.7	601	39.2	"	"
Wheeling	64,385	15.7	12.9	637	40.0	"	Surface

OHIO RIVER POLLUTION SURVEY

FINAL REPORT
TO THE
OHIO RIVER COMMITTEE

SUPPLEMENT "F"

BIOLOGICAL STUDIES

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
CINCINNATI, OHIO
1942

BIOLOGICAL STUDIES

Supplement "F" to
Final Report to the Ohio River Committee
Ohio River Pollution Survey

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
STREAM POLLUTION INVESTIGATIONS STATION
CINCINNATI, OHIO
1942

BIOLOGICAL STUDIES

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SUMMARY

The primary purpose of the biological studies in connection with the Ohio River Pollution Survey has been twofold: first, to determine present biological conditions as a record to be compared with conditions after future changes due particularly to remedial measures which may be instituted, and second, to determine the effect, particularly of a destructive nature, of present sources of pollution on stream biological communities and fish life as a guide in judging the need for corrective measures.

Secondary purposes include determination of what biological and chemical conditions may be typical of different pollutional situations, what factors under man's control are involved in creating these situations, and what combinations of these conditions may be allowed for designated stream uses.

This biological supplement is based upon extensive data obtained from the examination of plankton and fish collections and correlated with chemical and bacteriological findings. Fish collections were made only during the second year of study and did not include the middle third of the basin nor the main Ohio River.

Biological life is closely related to problems of stream sanitation. A change in the magnitude or the nature of the pollution load will almost without exception cause a change in the lower biological forms and, as these are food for fish life, fish, in turn, are also affected. An increase in the minute forms or plankton may affect water supply due to taste and odor troubles or filter clogging difficulties caused by certain types when present in large numbers.

While pollution is usually considered to damage or destroy aquatic life and recreational values and this is frequently the case, it is possible for moderate pollution to provide food material and increase aquatic life, particularly in an otherwise naturally barren stream. This might be termed a beneficial effect as far as fish life is concerned and may parallel a detrimental effect if the increase in plankton causes taste, odor and filter clogging difficulties in water supply systems.

Corrective measures in the nature of sewage treatment remove a portion of the organic pollution load and stabilize a further portion. Thus the destructive effect of pollution on aquatic life may be corrected and, at the same time, a large measure of the food material retained. An over-all benefit to

aquatic life may thus be accomplished by a treated effluent. Pollution has only a damaging effect on water supply, and treatment measures reduce this effect to a greater or lesser degree but never entirely eliminate all effects.

Pollutants which enter streams from city sewers or organic industrial plants, such as canneries, meat packing houses and creameries, affect the aquatic life in a variety of ways. The waste may have an immediate toxic effect on aquatic life or, more usually, the waste may induce rapid multiplication of aerobic bacteria which sharply lower the dissolved oxygen concentration, sometimes to the asphyxial level for fishes, or even to total depletion.

The lowering of the dissolved oxygen concentration to a point below 3 p.p.m., accompanied by a high oxygen demand and high coliform bacterial population, is evident in a zone of heavy organic pollution, below sources of pollution, the distance depending upon the temperature, rate of flow and physical character of the stream. Biologically, this region is dominated by bacteria-eating protozoa, colorless flagellates and chlorophyll-bearing flagellates that require a rich cultural medium. The fish are principally of the coarser varieties, such as carp and buffalo.

This zone gradually blends through an intermediate stage into a fertile zone which is characterized by a large variety and volume of photosynthetic plankton organisms and dissolved oxygen above 5 p.p.m. In this region is usually found a large mixed plankton population, reflecting the maximum fertilizing effect of the upstream pollution. Fish are varied and abundant, there being large numbers of market and food fishes.

Further downstream the plankton volume is diminished. This reduction in fish food has a direct effect upon the fish population, so that the game fishes are the dominant forms.

Industrial wastes such as effluents of coal mines, steel mills, paper and pulp mills, oil and gas refineries, in sufficient concentration, reduce the aquatic life, either by a direct toxic action or by a reduction in hydrogen ion concentration (pH 4.5 or less). The flesh of fish in streams polluted by oil refineries or paper mills is tainted and cannot be used as food.

The condition of a stream from a biological standpoint will vary with conditions. During spring high water, for example, zones of heavy pollution and intermediate zones are scarce. As the year advances and low-flow conditions set in, the polluted

areas are more distinct and it is the summer low water period that is critical to the fish population of a stream. A period which exterminates a fish population may be only one day of the year and it is not offset by the tolerable conditions of the other 364 days.

In general, localities where normal biological communities and fish life were found to be detrimentally affected or destroyed and pollutional forms found to predominate, corresponded to localities where information on sources of pollution and chemical and bacteriological data indicated that large sources of pollution exist. Outstanding examples are the upper Ohio River and tributary areas, where acid pollution, chiefly from mines, has destroyed all but the very specialized aquatic forms capable of existing in acid water, and below the larger cities and in some instances larger industries that continue to discharge wastes without treatment. Conditions below individual sources of pollution and in other areas throughout the basin are discussed in the drainage basin summaries.

INTRODUCTORY AND GENERAL

Authorization

This biological survey was conducted as part of the Ohio River Pollution Survey, authorized in Section 5 of the River and Harbor Act passed August 26, 1937. This section reads in part as follows: "The Secretary of War is hereby authorized and directed to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited directly or indirectly therein, and the sources and extent of such deposits, and with a view to determining the most feasible method of correcting and eliminating the pollution of these streams."

Activities in connection with the Ohio River survey have divided themselves into three broad groups: (1) The collection of data on water supply, sewerage, sewage disposal and industrial wastes,together with the location, character and amounts of polluting wastes; (2) Laboratory studies (biological, chemical and bacteriological) relative to the sanitary conditions of the streams at the time of sampling; (3) Hydrometric studies on the stream discharge, time of flow, and the possible dilution at the time of sampling.

When the survey was originally planned, the watershed was to be divided into three parts and a year was to be spent on each third. The middle third, from Point Pleasant, West Virginia, including the Big Kanawha Basin, to Carrollton, Kentucky, including the Kentucky River Basin, was studied in 1939. However, due to subsequent shortening of the time allowed for the survey, both the upper and lower thirds of the watershed were studied in 1940.

In order that this supplement may be complete in itself, certain data on stream flow, drainage basin characteristics, population, bacteriological data and chemical data,presented in the main body of the Ohio River Pollution Survey report, have been repeated.

The Scioto River has been studied as a separate project (U. S. Public Health Bulletin No. 276) and is discussed briefly in Appendix I to this supplement. The Tennessee River is being studied by the Tennessee Valley Authority, and that organization has submitted a brief progress report on the studies, which is presented as Appendix II to this supplement.

Personnel and Acknowledgments

The laboratory operations of the survey were performed under the administrative direction of Senior Sanitary Engineer J. K. Hoskins, in charge of the Stream Pollution Investigations Station at Cincinnati, who was succeeded in July, 1940, by Medical Director H. E. Hasseltine. The work was organized and carried out under the technical direction of Senior Sanitary Engineer H. W. Streeter, with Associate Biologist F. J. Brinley in immediate charge of the biological studies. Junior Aquatic Biologist L. I. Katzin assisted Dr. Brinley during the second year of the work.

Special Expert W. C. Purdy and Senior Biologist J.B.Lackey, from the regular staff of the Cincinnati station, co-operated in acting as technical advisers in various phases of the work. Dr. Lackey also prepared Appendix I to this supplement, covering biological studies on the Scioto River, based on his studies covered in Public Health Bulletin No. 276.

Numerous fish specimens were submitted to the Laboratory of Interior Fisheries Investigations, U. S. Bureau of Fisheries, under the direction of Dr. M. M. Ellis.

Grateful acknowledgment is made to Dr. E.L.Bishop,Director of Health of the Tennessee Valley Authority, for the "Discussion of the Biology and Pollution of the Tennessee River," which is included as Appendix II of this supplement. The appendix is a joint report of the Forestry Relations and the Health and Safety Departments and was prepared by Dr. A. H. Wiebe, Chief, and Dr. C. M. Tarzwell, Associate Aquatic Biologist, Biological Readjustment Division, Forestry Relations Department, and Mr. G. R. Scott, Senior Sanitary Engineer, and Dr. A. D. Hess, Assistant Aquatic Biologist, Health and Safety Department.

Physical Characteristics of the Ohio Basin

The Ohio River, which is formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania, drains an area of 204,000 square miles in the eastern central United States (Figure 1), including parts of the following fourteen states: New York, Pennsylvania, Maryland, Virginia, North Carolina, Ohio, Indiana, Illinois, West Virginia, Kentucky, Tennessee, Georgia, Alabama and Mississippi. The tributaries studied in the biological survey consisted of the Allegheny, Monongahela, Muskingum, Hocking, Little Kanawha, Kanawha,

Big Sandy, Little Sandy, Guyandot, Miami, Little Miami, Licking, Kentucky, Green, Wabash and Cumberland Rivers.

Limestone and shale are the common bedrocks found in the Ohio Basin. The northern section of the watershed is overlaid with glacial drift, forming the deep and fertile soils in the western section of the basin. In the Appalachian highlands, in the eastern part of the basin, the soil is light and sandy, while in the south central basin it is alluvial, consisting of a mixture of rich loam and clay. The important natural deposits are coal, iron, oil and gas. Portions of the Appalachian coal fields extend along the eastern section of the basin from western New York southwest to Alabama. The so-called eastern interior fields lie in parts of southwest Indiana, Illinois and western Kentucky. Oil and gas have been developed in the Appalachian fields of New York, Pennsylvania, Ohio, West Virginia and Kentucky, the Lima-Indiana fields in southwest Ohio and eastern and southern Indiana, and in the Illinois fields in central and southern parts of the state.

Three major physical divisions characterize the Ohio Basin. Rough hills and mountains of the Appalachian highlands prevail in the east. Low hills, of the interior plateaus, occupy the southwest. Gently sloping, glacial lowlands of the interior plains are found in the north and northwest.

Navigation on the entire length of the Ohio River, during all times of the year, has been made possible by the construction of fifty-three locks and dams providing a nine-foot low water channel. Locks and dams also have been built on the Allegheny, Monongahela, Muskingum, Kanawha, Kentucky, Green and Cumberland Rivers.

Introduction

There are two principal factors which influence all biological survival: (1) Self-preservation, which includes securing and assimilation of food, and escaping enemies, and (2) Race preservation, which includes reproduction in addition to the functions of self-preservation.

Food, therefore, becomes a very important and often the limiting factor in the life of an individual, race, or of a biological community. One aspect of the food relation of a community is expressed as the "food chain" or chemical cycle of the ecologist. Plants synthesize complex organic compounds

Fig. I


OHIO BASIN
FIG. I
LAKE ERIE
PENNA.
N. Y.
MD.
VIRGINIA
W. VA.
OHIO
INDIANA
ILLINOIS
KENTUCKY
TENNESSEE
N. CAR.
S. CAR.
GEORGIA
ALA.
MISS.
MO.
PITTSBURGH
CINCINNATI
LOUISVILLE
EVANSVILLE
NASHVILLE
KNOXVILLE
CHATTANOOGA
COLUMBUS
DAYTON
INDIANAPOLIS
CLEVELAND
CHICAGO
ST. LOUIS
MEMPHIS
WASHINGTON
BALTIMORE
RICHMOND
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
MARCH 1941

from soluble salts and carbon dioxide, either by means of solar energy through the agency of a pigment such as chlorophyll, or by means of other energy-yielding chemical reactions. These plants and their products may form food for various animals who, in turn, may be eaten by larger animals. Eventually, carbon dioxide is returned to the air, and soluble materials to the soil and water through the agency of the natural chemical processes carried on by the higher organisms, or through the destructive action of bacteria, molds and fungi upon organic material no longer living. Thus, the cycle is completed.

The other important aspect of the community food relation lies in competition for the same (usually) limited food supply between organisms not in the relation of prey and predator. In the process of organic evolution the competition for survival has led to such diversifications that there is usually a single species, or restricted group of species, best fitted to survive and reproduce under a given set of environmental conditions. Conversely, it is usual that a certain set of conditions must obtain before a given species can hold its own in competition with others.

The above considerations hold for the aquatic environment as well as for the terrestrial and aerial. The microscopic aquatic plants and plant-like animals synthesize organic materials from the chemical constituents of their fluid surroundings, under the influence of sunlight, giving off oxygen as a by-product. These minute organisms may form the food of larger Protozoa, of Mollusca, Rotifera, small Crustacea, and larval or even adult fishes. Such plankton-feeders may in turn form the food of larger fishes, and so on. Eventually, compounds of carbon no longer living (wastes, dead organisms) are returned to the water, and broken down through progressive steps, by the bacteria, untilnothing but soluble inorganic salts are left. and the cycle commences again. The amount and kind of aquatic life depends ultimately upon the concentration and availability of food in the stream. Thus, a stream may be considered as a nutritive medium for the life growing therein.

Many factors may temporarily interrupt or modify the chain of events, as by removing certain links such as the fish, or by adding organic material in bulk. The most significant factors are man's activities. For the moment attention will be focused on the material he places in the water, hereafter termed "pollutants."

For practical reasons, it is necessary to limit the discussion of this matter to the two ends of the food chain - the

microscopic forms that turn material in solution into their own organic substance, and the fishes. The intermediate forms are all important, but are eventually dependent upon these lowest forms. The fish, in turn, are the members of the aquatic community that come most directly to the attention of man, and are most usually his immediate concern.

A small stream which has just received a heavy load of domestic sewage can be taken as an example. This sewage is compounded of human excrement, waste food, paper, etc. It is immediately attacked by the bacteria of the stream. Such a point of gross pollution is characterized by large numbers of coliform bacteria (from excrement), a high rate of oxygen consumption, due to organic material being oxidized, a low dissolved oxygen value due to the use of the oxygen by the rapidly multiplying bacteria, and usually a low population of phytoplankton (plant plankton forms). This deficiency of plankton may be due to general toxicity of the sewage, particularly if industrial wastes are involved, and of the initial by-products of bacterial decomposition, and to the lack of available food materials in solution.

Several species of bacteria-eating Protozoa, such as _Paramecium_, _Stentor_, _Colpoda_, _Glaucoma_, _Colpidium_, _Vorticella_ and _Carchesium_, may occur in significant numbers in grossly polluted areas, more abundantly in the slime and scum on stones and sticks and on the surface of the bottom mud than in the plankton. Fish, with the possible exceptions of buffalo and carp, are absent under these conditions. As the sewage moves downstream, the complex organic compounds are reduced by bacterial and chemical means to simpler chemical compounds. Certain microscopic plants, such as _Euglena_, _Lepocinclis_ and _Phacus_, which thrive in a medium rich in organic material, may make their appearance in large numbers. As chemical breakdown continues, these plants will give way to _Pandorina_, _Eudorina_, _Trachelomonas_, _Scenedesmus_, _Chlamydomonas_ and _Mallomonas_. Certain Protozoa, such as _Domatomonas_, _Codonella_, _Strobilidium_, _Strombidium_ and _Cyclidium_, may appear, but never abundantly. Further downstream, various species of _Chrysococcus_, _Cryptomonas_, _Chroomonas_ and _Dinobryon_ are found in large numbers where the water is approaching purity. Plankton is scarce except for diatoms and these last named forms in streams that receive no organic pollution of any sort.

It is apparent that domestic sewage acts as a fertilizer for aquatic plants in the same manner as organic matter does for land plants. The carbohydrates and proteins in fresh sewage are not equally available for all plant growth and meet the

nutritional requirements of different organisms in succession during the series of changes leading to inorganic end products. The order of development of the various species of planktonts depends upon their reaction to the concentration of these various products. Chrysococcus and Cryptomonas are found in the cleaner portions of watercourses low in organic matter. Many species of Euglena prefer polluted streams (rich medium) where purification of the sewage has not approached completion. Pandorina and Trachelomonas may be considered as intermediate forms, preferring culture media of lower organic concentration. So, in the natural course of events, the highest population of plankton occurs at some distance below the source of pollution, where the concentration of soluble materials is suitable for the largest number of species.

Fish life increases in regions where the heaviest plankton populations occur. The plankton furnishes food directly for many larval and some adult fishes and also for water fleas, rotifers, etc., which are important foods for larger fish. The phytoplankton, through the process of photosynthesis, produces oxygen which may be of considerable importance in maintaining a high dissolved oxygen concentration. The coarse fishes are found nearest the source of pollution and game fish appear further downstream.

Beside the presence or absence of sewage, the plankton population is influenced by temperature, hydrogen-ion concentration, turbidity, variations in stream flow, and seasonal changes. Plankton develops more rapidly at higher water temperatures, while sudden temperature drops reduce the plankton population. At temperatures of 10° C. or lower, a large proportion of the plankton organisms disappear. Certain species will withstand lower temperatures than others. Chrysococcus can be collected when the stream is frozen over. Variations in the hydrogen-ion concentration between pH 6 and 8.5 seem to have little, if any, effect on plankton. Higher acidities (pH 4 or less), resulting from acid pollution, may destroy all plankton except a few resistant species.[1]

A sudden rise following rain will often flush out plankton, and several days may elapse before the organisms again appear in numbers. High turbidity following rain is also detrimental to plankton. A slow-moving stream which gives more time for bacterial action is more suitable for the development of plankton organisms than a rapid stream. Pool conditions during low flow may result in the development of a large number of certain species not normally present in such numbers. These may be distributed several miles downstream by increased flow following

rains. Conversely, a rain may wash the plankton out of a swamp or oxbow lake into the main stream, thereby causing a sudden increase in the amount of plankton. The constant flow of a stream will carry plankton a distance downstream, and a peak in the plankton population may slowly travel the entire length of the stream.

In the discussion to follow, the effects of pollution introduced directly or indirectly by man will be considered from the standpoint of the changes in food supply and the various "ecological niches" along the watercourse. Only the protozoan and normal algal constituents of the plankton will be considered, together with the fish.

Method and Procedure

The majority of the plankton samples were taken with those for the chemical and bacterial studies, by collecting 250 ml. of water a short distance below the surface. Samples were taken once each week at certain key points along the Ohio River and its tributaries, while at other points samples were taken only once, or at irregular intervals. Samples were brought to the Cincinnati laboratory either fresh or preserved in 4 per cent formalin. One hundred cubic centimeters of the water was centrifuged for five minutes at a speed of about 2,500 r.p.m. The supernatant liquid was decanted, leaving the organisms originally present concentrated in about one cubic centimeter of fluid, the exact amount being determined by a pipette, delivering 25 drops per cubic centimeter. The number of organisms in one-fourth of the "catch" was determined by counting under the low and high powers of a compound microscope. The number of organisms was computed per cubic centimeter of the original sample. For a detailed report of the method, see Lackey.[2]

The results of the plankton determinations are given in the tables in numbers per milliliter for the various taxonomic groups. The plankton volume is expressed in thousands of parts per million (M.p.p.m.). Volumes were determined by multiplying the number of individuals of the various species by the volume of an average individual of the species. These average volumes were obtained from figures of Lackey and Kehr (unpublished). The volume curves in the graphs are subdivided to show the proportion of Class I, Class II and Intermediate organisms. Class I organisms are those which tend to favor water of good sanitary quality and are able to survive scarcity of organic food, sudden changes of and low temperatures, and relatively high acidity.

In this class are included such genera as Chrysococcus, Cryptomonas, Dinobryon, Chromulina, and the various genera of diatoms (Bacillarieae) encountered. Class II is made up of those forms which favor a rich nutritive medium or feed upon bacteria and solid particles. In this group are included Euglena, Lepocinclis, Phacus, Synura, Anabaena, and the bacteria-eating ciliates such as Paramecium, Colpidium, Vorticella, etc. All planktonts not definitely falling into the above extreme groups are lumped together as Intermediates.

It is clearly realized that these genera are not homogenous but that certain species differ in their food requirements and tolerance to environmental conditions. Owing, in many cases, to the inability to determine species in formalin-preserved samples, it was considered more advantageous to keep the above grouping and to note particular cases where inconsistencies may be due to species differences. The principal example is Euglena mutabilis, found in abundance in acid streams which are free of organic pollution, which would indicate that it belonged to Class I. Likewise, Stephanodiscus, found in the Wabash Basin, has a distribution which would indicate that it belonged to Class II. In these studies, however, these exceptions were not separated from their taxonomic groups, Euglena and the Bacillarieae, respectively.

Fish collections were made where possible in the upper and lower thirds of the watershed by means of seines and a trap net (fyke net). No fish collections were made during the season of 1939 in the middle third of the basin. Whenever fish collections were made, plankton and chemical samples were taken. Information on fish life was obtained whenever possible from local fishermen and residents. Results of the biological studies have been compared and correlated in this report with the chemical and bacteriological findings.

In the following discussion, certain terms will recur repeatedly. Pollutants shall be defined as any material introduced into the stream from without, usually of an organic nature. The symbol "D.O." refers to dissolved oxygen, measured in parts per million by the Rideal-Stewart and azide modifications of the Winkler method. The term "B.O.D." (biochemical oxygen demand) refers to the amount of oxygen disappearing from a sealed sample of water at 20° C. in the course of five days (due to microorganismal action), and is usually expressed in parts per million. Alkalinity is a measure of the carbonate and bicarbonate buffering capacity of the water, determined by titration with dilute sulfuric acid using methyl orange indicator. Acid activity is expressed in the usual pH units. In this report, wherever acidity

is used, it refers to acid activity as expressed by the term "pH."* Turbidity was determined by the Jackson turbidimeter and is given as parts per million. "Coliform organisms" refers to bacteria of the coli-aerogenes group, given in most probable numbers per milliliter. These determinations follow the procedure given in Standard Methods of Water Analysis (American Public Health Association, 8th Edition, 1936). The azide modification of the Winkler D.O. determination is that of Ruchhoft, Moore, Placak.[3]

The figures following the word "mile" refer to the mileage from the junction of the tributary in question with the Ohio River, except the White River, where the mileage given is taken from its junction with the Wabash River. The mileage on the Ohio River is taken from the confluence of the Allegheny and Monongahela Rivers at Pittsburgh. On curves showing volume of plankton in thousands of parts per million (M.p.p.m.) the upper line represents the total volume, the space between the upper and middle line represents the volume of intermediate organisms, the space between the middle and lower line represents the volume of Class II organisms, and the lower line represents Class I organisms.

* The pH is the logarithm of the reciprocal of the hydrogen ion concentration and can be considered a measure of the acid intensity when the pH is below 7.0 It is suggested that the term "acid intensity" be substituted for "acid activity as given above. Strictly, the term "acidity" refers to the titratable acid as determined with standard alkali using methyl red or a similar indicator. Titratable acidities were not determined in the biological studies and the common meaning is not implied here. Wherever the term "acidity" is used in this report, it refers simply to a pH value below 7.0 On the other hand, a pH value above 7.0, indicating an alkaline reaction, is referred to as an "alkalinity."

In this class are included such genera as Chrysococcus, Cryptomonas, Dinobryon, Chromulina, and the various genera of diatoms (Bacillarieae) encountered. Class II is made up of those forms which favor a rich nutritive medium or feed upon bacteria and solid particles. In this group are included Euglena, Lepocinclis, Phacus, Synura, Anabaena, and the bacteria-eating ciliates such as Paramecium, Colpidium, Vorticella, etc. All planktonts not definitely falling into the above extreme groups are lumped together as Intermediates.

It is clearly realized that these genera are not homogenous but that certain species differ in their food requirements and tolerance to environmental conditions. Owing, in many cases, to the inability to determine species in formalin-preserved samples, it was considered more advantageous to keep the above grouping and to note particular cases where inconsistencies may be due to species differences. The principal example is Euglena mutabilis, found in abundance in acid streams which are free of organic pollution, which would indicate that it belonged to Class I. Likewise, Stephanodiscus, found in the Wabash Basin, has a distribution which would indicate that it belonged to Class II. In these ... these exceptions were not separated from their ... the Bacil-
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The biological data collected during the Ohio River Pollution Survey are discussed briefly in summaries covering the individual tributary drainage basins and the main Ohio River. The tributary summaries have been grouped in the middle, upper and lower thirds of the Ohio River Basin and are discussed in that order. The middle third tributaries are discussed first, as the first year of study was spent in this area and many more samples were examined than was possible in the case of the upper and lower thirds. The Scioto River in the middle third is discussed in Appendix I, and the Tennessee River in the lower third is discussed in Appendix II. The Beaver River in the upper third was not covered, due to time limitations.

Middle Third

Miami River

The Miami River rises in the west-central part of Ohio in Logan County, near the village of Bell Center (elevation 980 feet). The stream starts as a small brook, meandering through a wide valley, and flows the short distance to Indian Lake, the largest body of water within the state. From Indian Lake, the stream continues in a westerly direction to Dayton (90 miles), where it is joined by the Mad and Stillwater Rivers. At Dayton the direction of flow shifts toward the southwest corner of Ohio. The Miami is joined by the Whitewater River of Indiana at a point 4.8 miles from its mouth and thence flows into the Ohio River near Cleves, at the Ohio-Indiana state line.

The Miami Basin comprises a total area of 5,385 square miles, of which 1,590 square miles are in the Whitewater Basin mostly in Indiana. Flood control dams have been constructed at Englewood on the Stillwater, at Phoneton on the Miami above Dayton, and on the Mad River above Dayton.

The northern part of the basin is level to gently rolling; the soils are rich, and agriculture is prosperous. The southern part is more eroded, the slopes are steeper and soils less fertile than in the northern part. The rocks which underlie the basin are limestone and shale. The average slope below Middletown (mile 53.6) is about 3.6 feet per mile, and the maximum and minimum discharges at the mouth of the river are 478,000 and 340 (summer minimum at Hamilton) cubic feet per second, respectively.

The population of the Miami Basin was about 830,000 in 1940. Over sixty per cent of the population was urban and ten per cent more lived in incorporated towns of less than 2,500. The population density was about 155 per square mile, considerably above the average for the entire Ohio Basin. The population density of the Indiana portion of the basin was about 75 and the Ohio portion about 183 per square mile.

The principal cities in the Miami Basin are Dayton, Springfield, Hamilton, Middletown and Piqua, Ohio, and Richmond and Connersville, Indiana. The total population of these towns is 427,286 (1940), which is more than half the population of the basin. All of these cities are industrial and manufacturing centers. The principal products are paper, machinery and tools, sheet metal and textiles.

In order to study the seasonal distribution and variation of plankton, a series of samples was taken at Cleves at weekly to biweekly intervals, from May 16 to December 12, 1939. The results are shown in Figure 2 and Table 1. The first sample was taken on May 16 when the turbidity was low (about 10 p.p.m.). The plankton volume was high, largely due to diatoms. The high D.O. value of about 10 p.p.m. is, in all probability, due to the large plankton population. During the six-week period between this date and June 26, more than three inches of rain fell. Owing to the high turbidity, plankton samples were not taken. On June 26 the water had cleared sufficiently to continue plankton examinations. The total plankton volume was low, due, no doubt to previous high turbidity and the flushing out of the stream by the frequent rains. This was reflected in the low coliform organism count and low B.O.D.

On July 11 the turbidity was again high, due to previous rains, and the plankton was washed out of the river. July 17 showed a slight recovery of plankton, accompanied by a drop in turbidity. The plankton population again started to rise on August 2, reaching the highest value of the summer - about 10 M.p.p.m. - on August 28. Rain on September 4 may have influenced the drop in the plankton population.

The plankton rose slowly to about 4 M.p.p.m. in the next several weeks, until the advent of cold weather. The temperature dropped to 12° C. on October 17 and continued falling to 7° C. on December 12. This resulted in great depression of the plankton population other than diatoms. During this period the river was in a stable condition as light rains fell only occasionally.

A series of samples was collected at various stations from Cleves to Miamisburg at intervals from June 27 to October 26. The results are plotted in Figures 3 and 4. The figures indicate that there is a strong tendency for the dissolved oxygen and the B.O.D. to vary inversely, and for the B.O.D. and the number of coliform organisms to vary in the same direction. Exceptions occur after the middle of August, a majority of which may be fairly readily explained.

Thus, the unexpectedly high dissolved oxygen values found along the river on August 17 seem to be attributable to the high plankton volumes of that date. This relation of the plankton to dissolved oxygen is also indicated at stations above Middletown and near Troy and Piqua on the upper river on September 14. The erratic values for August 31 cannot be readily explained. It should be pointed out, however, that after July the river was in low-flow "pool" condition, the characteristics of a stream at low water being quite different than during high water.

A further element complicating the coliform organism - B.O.D. - D.O. relationship at this season is the introduction of organic industrial wastes, which have high B.O.D. values in the stream, are not accompanied by coliform organisms, and have a variable availability as food for the plankton. Cannery wastes may be mentioned as typical of this class of pollutants. Such material may account for the high B.O.D. observed below Hamilton on September 29, as well as other discrepancies noted in the curves. Certain other irregularities, such as the dissolved oxygen peak at Franklin on September 29, are not at present to be explained. The unpredictably high dissolved oxygen value at Cleves on October 26 is presumably related to the lower water temperature and greater oxygen solubility at the lower temperature. Other oxygen differences, such as the absence of a sharp oxygen peak at Sidney, September 24, to correspond with the plankton peak, may be due to the difference in composition of the plankton compared with the plankton further downstream (diatoms instead of flagellates of various kinds).

There are certain fairly definite seasonal and weather influences affecting the plankton. Summer warmth, sunshine and low water tend to increase the plankton population, aided by the low turbidity of this season. Rains tend to wash out the stream and deplete the plankton (the curve of August 3 shows the condition following heavy rain), and low or rapidly dropping temperatures take heavy toll of the less-resistant planktont. In addition to these general factors, a stream such as the Miami shows characteristic effects of the various sources of pollution along its course.

Hamilton, with a sewered population of 54,600, no sewage treatment plant, and many industries - coke plant, textile mill, meat packing house, paper mills and several creameries - tends to raise the volume of the river plankton, with the peak occurring further downstream, as at Venice, and Class II organisms form a large portion of the plankton.

Middletown, with a sewered population of 35,000 and no sewage treatment plant, has a number of paper mills, and it is probably the effect of this heavy load of industrial waste that causes a sharp local depression of the plankton volume. During summer conditions this depressive action may not be well marked. The peak of the Middletown fertilization effect probably comes somewhere in the vicinity of Hamilton.

Franklin is a smaller town, having a sewered population of 4,000, and several paper mills. The town has a secondary sewage disposal plant under construction (1939). In general, there is a rise in the plankton population immediately below Franklin. The only exceptions to this occur in the series of July 20 and September 29. The factors involved here are not known.

Miamisburg has a sewered population of 5,300, two paper mills, and a tobacco plant. The absence of a sewage disposal plant is shown in the lowering of the plankton population of the Miami River as it passes the city. Exceptions to this generalization are shown in the curves of August 3, 31, and September 14. The reasons for this are not clear, but it may be pointed out that this is the period of low water and slow flow, and Miamisburg is a relatively small town.

Of the upstream samples included in the figure for September 14 (Figure 4), Tipp City, with a secondary sewage treatment plant under construction (1939) to serve 2,500 people, raised the plankton volume; Troy, with a chemical precipitation sewage plant under construction to serve 9,800 people, depresses the plankton population; Piqua, with a chemical precipitation sewage plant under construction (1939) to serve 15,800 people, and with a brewery, a cannery and a meat packing house, causes a slight depression of the plankton recorded at that location.

Sidney has a sewered population of 9,500, but no treatment plant. In addition, creameries, a brewery and a meat packing house supply a heavy industrial load. The meaning of the sharp peak of diatoms at this point is not clear. It may be indicative that one genus of diatom in particular in involved, *Navicula*.

The heavy plankton noticeable in the samples from above Miamisburg, resulting in a considerable volume of Class II planktonts below Miamisburg, in addition to the contribution from that city, must be attributed to the influent from the Dayton urban area, at about mile 85.

The flora and fauna of the Miami are abundant in species and numbers. This is especially true at all stations below Dayton and is due without doubt to heavy pollution load from the cities situated along the stream. These communities are discharging wastes into the stream at close intervals. The river does not recover from one heavy pollution loading before the next load of pollution is received. It is, therefore, difficult to study any one city separately and determine to what degree it affects the stream.

Samples collected during July and August indicate that the Mad River, which joins the Miami above Dayton, is a clear stream, as shown by the lack of organisms other than diatoms. Good trout fishing is reported in this stream at West Liberty. The Stillwater, another tributary which joins the main stream at Dayton, shows heavy pollution at Englewood, where a sample was taken on July 24. This may be due to accumulation of end products from the sewage of towns further upstream. Twin Creek and Seven Mile Creek, which are clear tributaries, enter the Miami at Franklin and Hamilton respectively. Four Mile Creek, which is polluted at Oxford, enters the Miami at mile 38.0.

The Whitewater River, which enters the Miami above Cleves, contained large numbers of Euglenophyceae below Harrison, and in the East Fork above Brookville, indicating heavy pollution at these points.

Little Miami River

The Little Miami River has its source in Clark County, Ohio, southeast of Springfield, and flows in a southwesterly direction for 100 miles. It joins the Ohio River within the city limits of Cincinnati, Ohio. The entire drainage basin lies southeast of the Miami watershed and drains an areas of 1,755 square miles. The headwaters have an elevation of 1,150 feet and the river gradient averages about 6.5 feet per mile.

Agriculture is the chief industry throughout the Little Miami Basin. Very little manufacturing is done. Seasonal canning of truck crops, with the waste products entering the

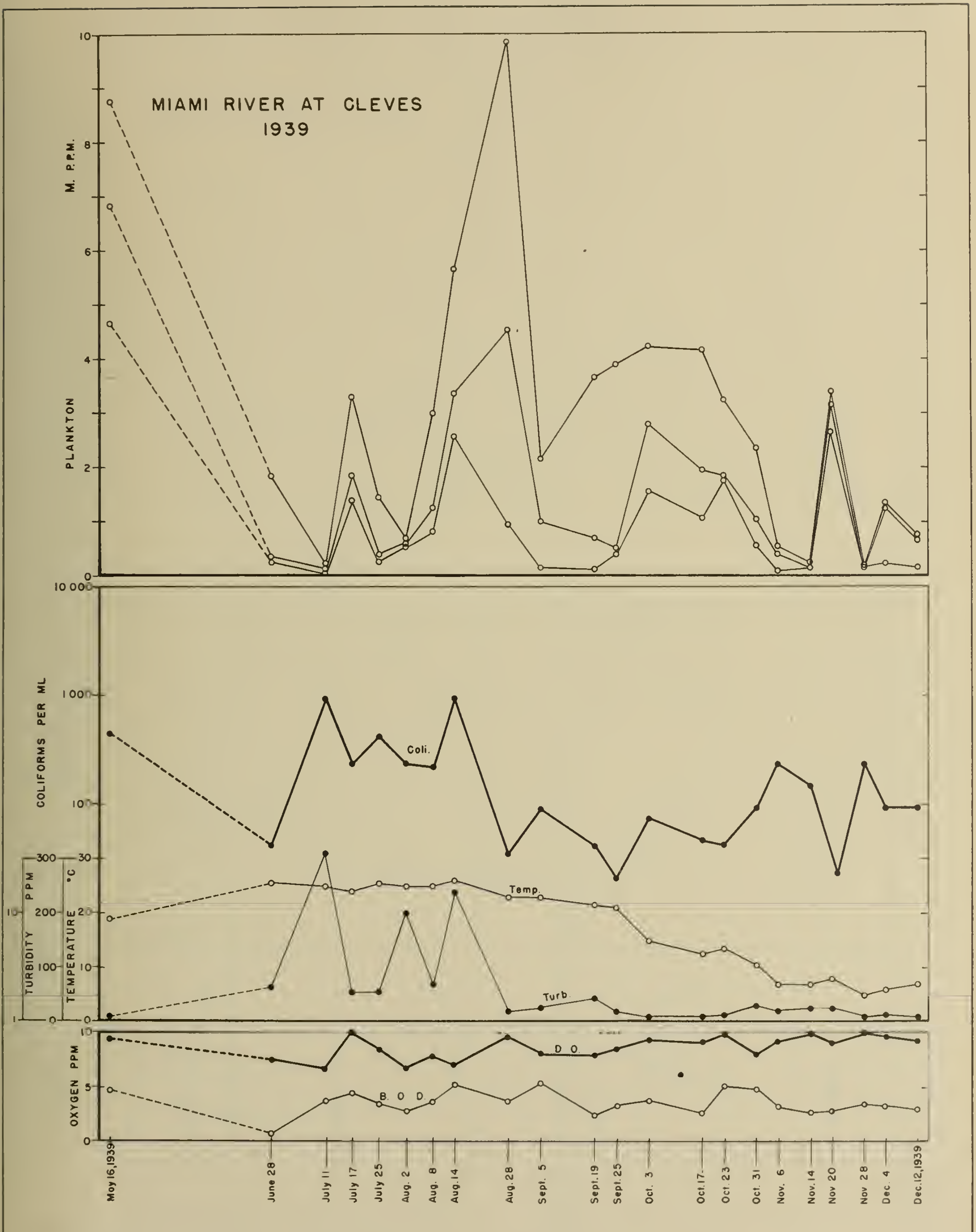

MIAMI RIVER AT CLEVES
1939
PLANKTON M. P.P.M.
COLIFORMS PER ML
Coli.
TURBIDITY PPM
TEMPERATURE °C
Temp.
Turb.
OXYGEN PPM
D. O.
B. O. D.
May 16,1939
June 28
July 11
July 17
July 25
Aug. 2
Aug. 8
Aug. 14
Aug. 28
Sept. 5
Sept. 19
Sept. 25
Oct. 3
Oct. 17
Oct. 23
Oct. 31
Nov. 6
Nov. 14
Nov 20
Nov 28
Dec. 4
Dec. 12,1939

Fig. 3

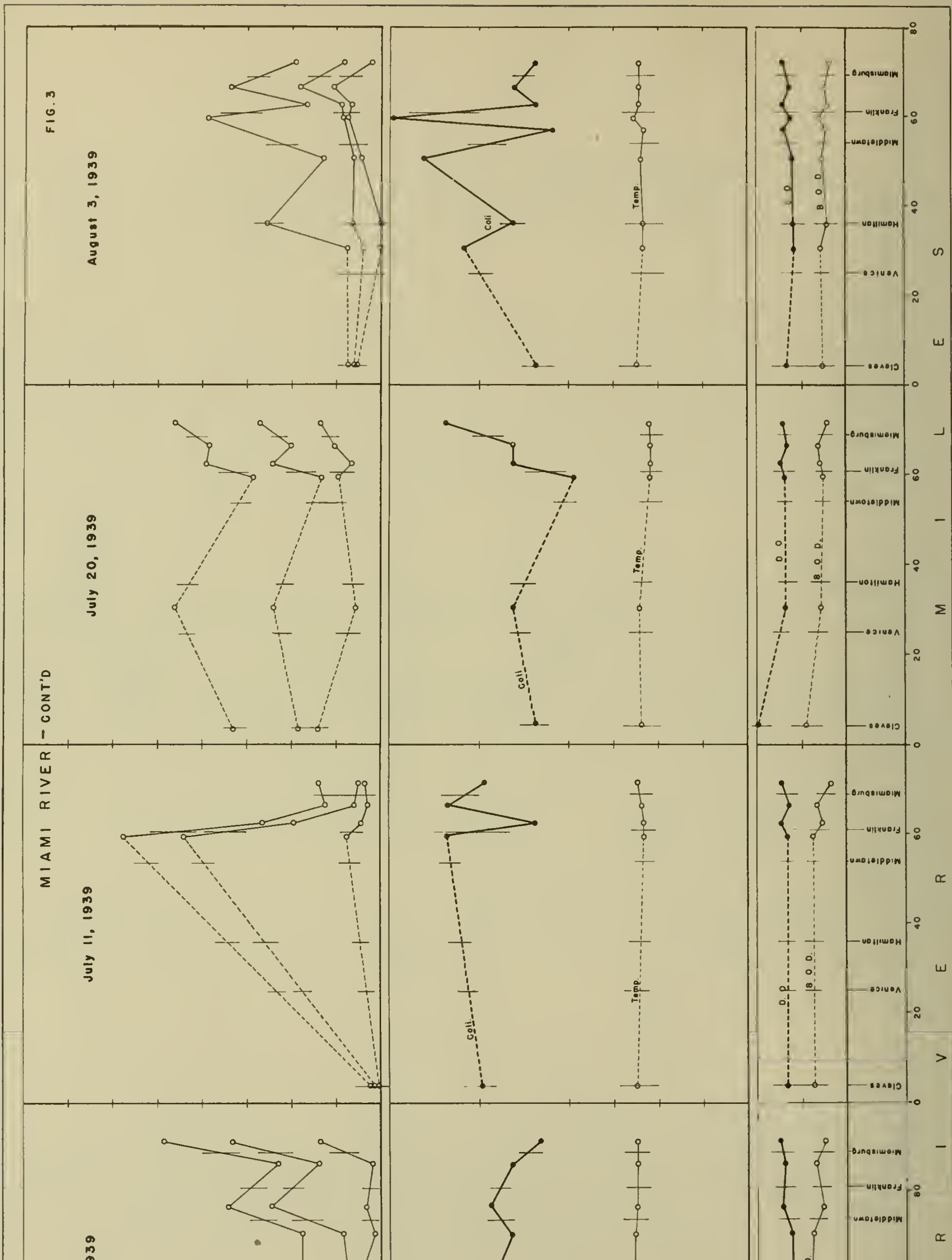
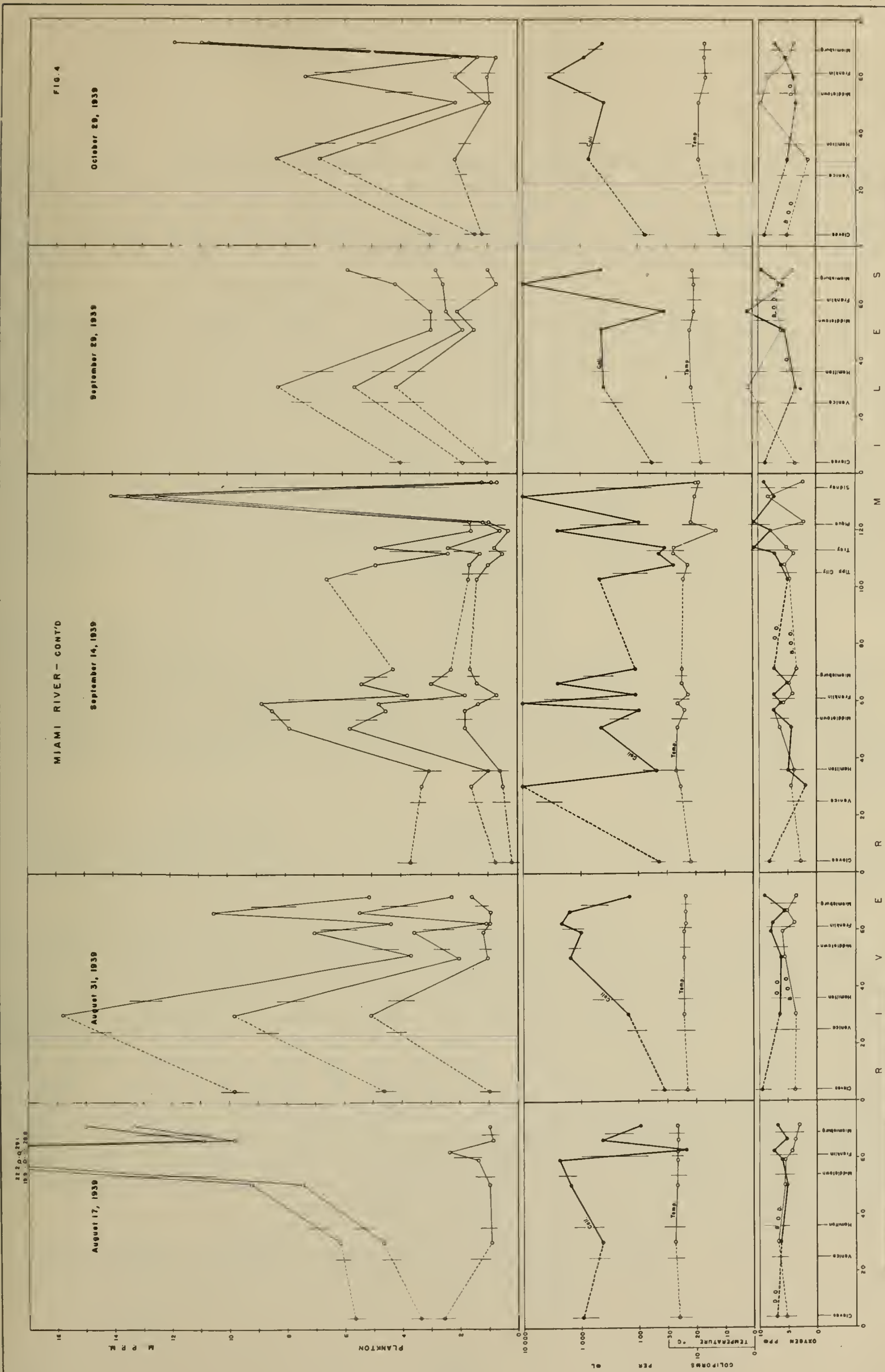


FIG. 3
MIAMI RIVER - CONT'D
June 27, 1939
July 11, 1939
July 20, 1939
August 3, 1939
PLANKTON M PPM
COLIFORMS PER ML
TEMPERATURE °C
OXYGEN PPM
Coli.
Temp.
D. O.
B. O. D.
Cleves
Venice
Hamilton
Middletown
Franklin
Miamisburg
R I V E R M I L E S

FIG. 4


MIAMI RIVER - CONT'D
August 17, 1939
August 31, 1939
September 14, 1939
September 29, 1939
October 20, 1939
FIG. 4
PLANKTON
COLIFORMS PER ml
TEMPERATURE °C
OXYGEN PPM
Temp
Coli
B.O.D.
Cleves
Venice
Hamilton
Middletown
Franklin
Miamisburg
Tipp City
Troy
Piqua
Sidney
R I V E R   M I L E S

river, creates a definite stream pollution problem. The total population of the basin, excluding part of the Cincinnati area, was 135,474 in 1940, of which 24,004 reside in the 41 incorporated communities. The principal communities are Xenia (pop. 10,633), Wilmington (pop. 5,971), and Lebanon (pop. 3,890).

A series of samples was taken at Beechmont on the Little Miami River from May 5 to November 20, 1939, with the exception of a period between June 8 and July 31, at which time heavy rains occurred (Figure 5 and Table 2). The B.O.D. was consistently low until August 15, at which time it showed a slight increase, reaching a peak on September 11, during the low water period. An unexplained drop occurred September 25, followed by a consistent rise up to November 6. A slight drop occurred on November 20. The D.O. also showed a decided drop to 3 p.p.m. on September 25, followed by a constant rise up to November 20, at which time it reached the peak of the season due to low temperature at that time. The coliform organism curve is very uniform along the river from July 31 to November 22.

During the period from July 31 to August 2 the small towns along the stream seemed to have no effect on the plankton population (Figure 6 and Table 2). During the rest of the season, however, the plankton dropped below South Lebanon and there followed, in most cases, a gradual rise to the mouth at Beechmont. However, on November 17 the plankton showed a decided drop below Milford.

During the week of September 22-27 a tremendous rise in the plankton occurred below the mouth of Yellow Springs Creek, due, no doubt, to a heavy pollution load from Yellow Springs.

A series of samples was taken along the East Fork and Turtle Creek, important tributaries of the Little Miami. Batavia and Waynesburg (secondary sewage treatment plant since constructed) discharged a small amount of untreated sewage in the East Fork, which, however, is not sufficient to cause a decrease of plankton but keeps the stream fertilized. Turtle Creek shows clearly the effect of heavy pollution on the plankton of a small stream and the rate of recovery of such a stream. The heavy discharge of sewage from Lebanon (chemical precipitation sewage plant since constructed) on July 19, August 2 and October 22, destroyed most of the phytoplankton in the stream immediately below town, but the plankton was present at South Lebanon about 3.5 miles further downstream.

The same condition occurs on Shawnee Creek. Below Xenia on August 25 it was observed that most of the plankton except

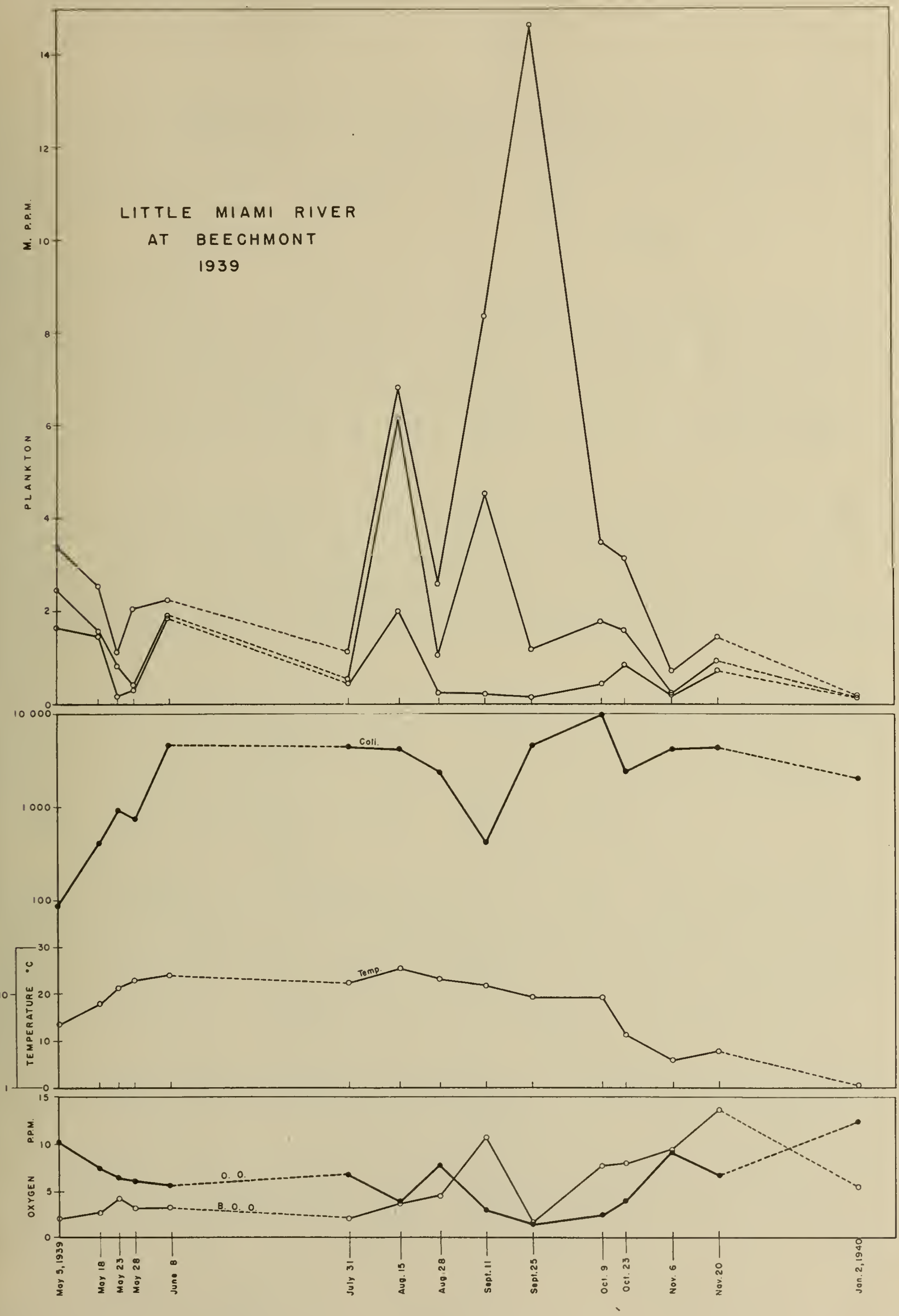
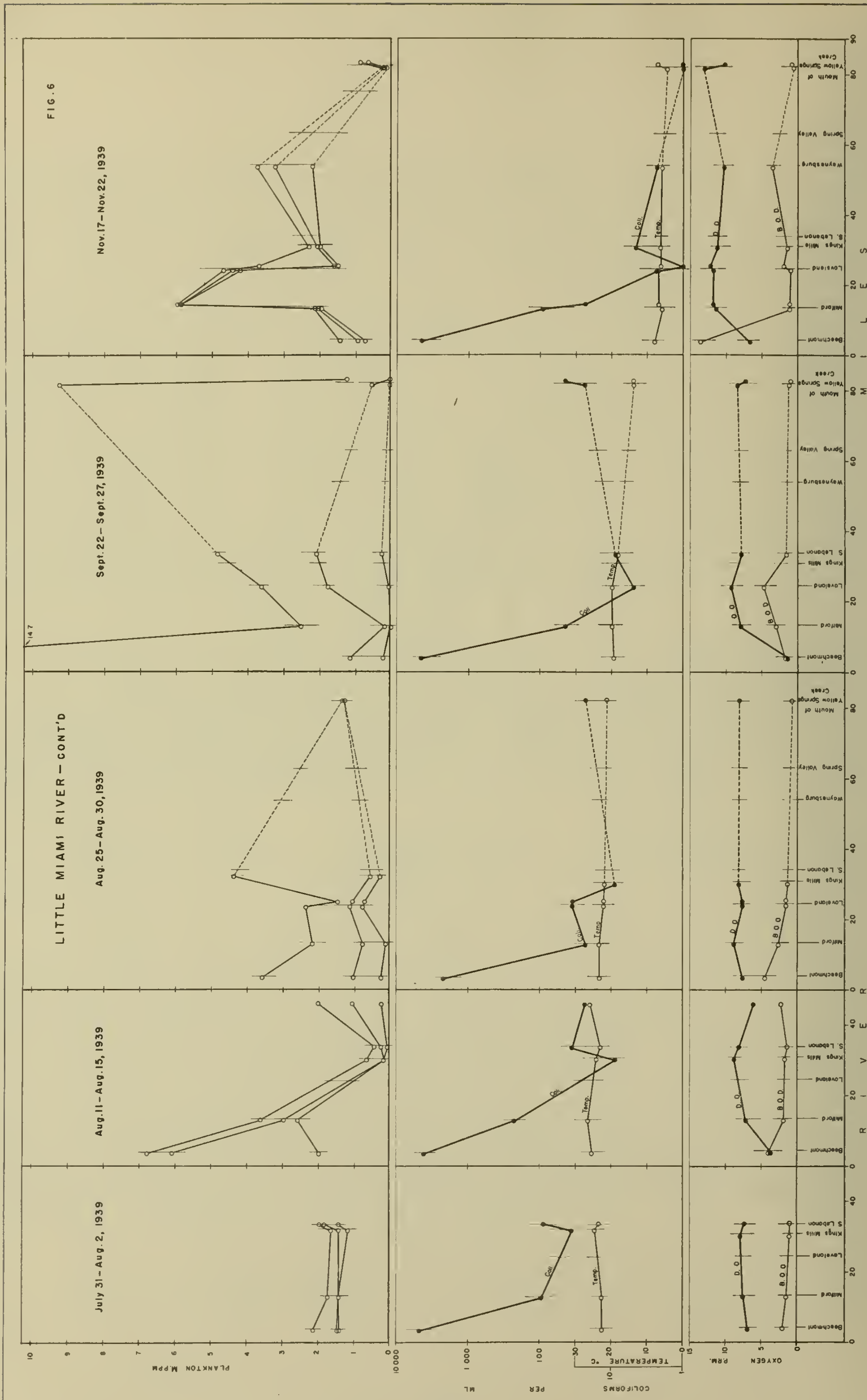

LITTLE MIAMI RIVER
AT BEECHMONT
1939
PLANKTON M. P.P.M.
COLIFORMS PER ML
Coli.
TEMPERATURE °C
Temp.
OXYGEN P.P.M.
O. O.
B. O. O.
May 5, 1939
May 18
May 23
May 28
June 8
July 31
Aug. 15
Aug. 28
Sept. 11
Sept. 25
Oct. 9
Oct. 23
Nov. 6
Nov. 20
Jan. 2, 1940

FIG. 6


LITTLE MIAMI RIVER — CONT'D
FIG. 6
July 31 – Aug. 2, 1939
Aug. 11 – Aug. 15, 1939
Aug. 25 – Aug. 30, 1939
Sept. 22 – Sept. 27, 1939
Nov. 17 – Nov. 22, 1939
PLANKTON M. PPM
COLIFORMS PER ML
TEMPERATURE °C
OXYGEN P.P.M.
Coli.
Temp.
D.O.
B.O.D.
Beechmont
Milford
Loveland
Kings Mills
S. Lebanon
Waynesburg
Spring Valley
Mouth of Yellow Springs Creek
RIVER MILES

the diatoms, Cyclotella and Navicula, were destroyed. A possible discharge from the heavily overloaded treatment plant may have been the cause. The contrasting plankton population of Lytle Creek, below Wilmington, may be due to the chemical precipitation treatment plant.

Licking River

The Licking River rises in the mountains of southeastern Kentucky in Magoffin County, flows in a northwesterly direction across the state and joins the Ohio River between Covington and Newport, opposite Cincinnati, Ohio. The total length is about 320 miles, with a watershed area of 3,670 square miles. Its average slope below Farmers (mile 172.5) is 1.2 feet per mile.

The upper portion of the Licking Basin lies in the mountains. The remainder is in the Bluegrass region. The underlying rocks are principally sandstone, shale and coal. The population of the mountainous region has a density of about 42 per square mile. There are only four incorporated towns in this section, the largest being West Liberty with a population of 573 (1940).

Morehead (pop. 1,901) and Farmers (pop. 296) are the only two incorporated towns in the transition zone between the mountains and the Bluegrass. The Bluegrass section is gently rolling and highly fertile. Four urban communities are in this area: Winchester (pop. 8,954), Paris (pop. 6,697), Cynthiana (pop. 4,840), and Mt. Sterling (pop. 4,782).

Samples at the mouth of the Licking River (Latonia) were taken from May 3 through November 13, 1939. The highest values observed for plankton were during the period from the middle of September to the middle of November (Figure 7, Table 3). The September peak was composed largely of the diatom, Cyclotella, while the peak of November 6 is due mainly to Chlamydomonas. Large numbers of Chrysococcus were found on November 13.

The depression in the plankton curve on May 25 is due to heavy rains between May 17 and May 25. This is accompanied by an increase in the coliform organisms that may have been washed into the river. The coliform count was very low for the remainder of the period of observation. The B.O.D. values were all below 2.5 p.p.m., and the D.O. curve seems to follow the influence of temperature more than any other single feature. The nearest point of any considerable pollution on the Licking

Fig. 7

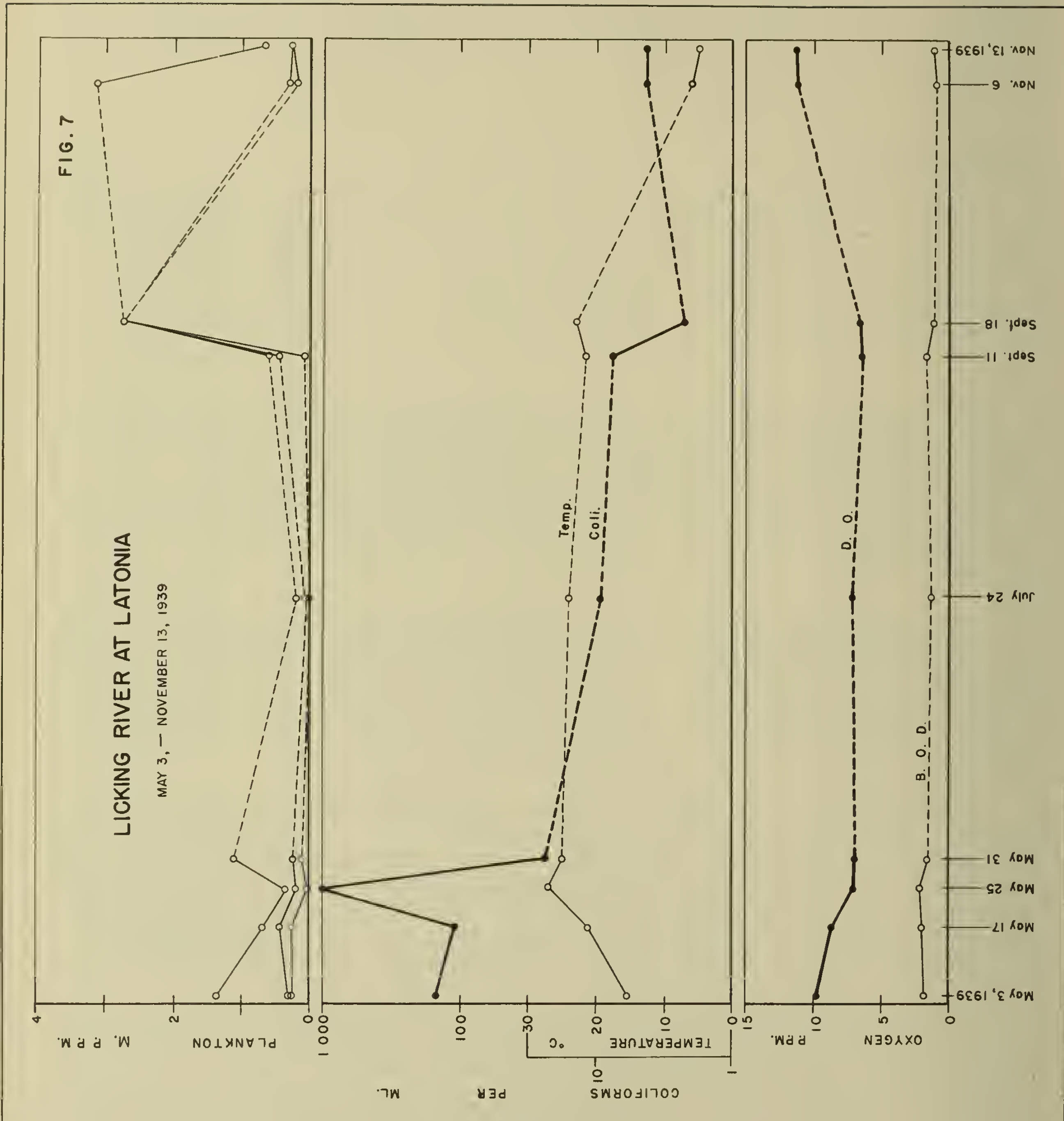


FIG. 7
LICKING RIVER AT LATONIA
MAY 3, — NOVEMBER 13, 1939
PLANKTON
M. P. P. M.
COLIFORMS PER ML.
TEMPERATURE °C
OXYGEN
P. P. M.
Temp.
Coli.
D. O.
B. O. D.
May 3, 1939
May 17
May 25
May 31
July 24
Sept. 11
Sept. 18
Nov. 6
Nov. 13, 1939

River is a creamery plant at Falmouth, which is some fifty miles up the river.

Samples were collected on the Licking River from Falmouth (mile 51) to Farmers (mile 172.5). Clayville (mile 82) appears to be a source of slight pollution. The stream also shows some contamination from Blue Lick (mile 100). Fleming Creek, entering a few miles above Blue Lick, is heavily polluted below Flemingsburg, but seems to have recovered before entering the Licking. The large numbers of Chrysococcus in the headwaters above Farmers and in many of the smaller tributaries indicate that these streams are comparatively free from domestic pollution. Some of the smaller creeks (runs) at Salyersville are contaminated with acid mine drainage.

The South Fork was studied by examination of samples collected at Falmouth (mile 51), Cynthiana (mile 82), and Lair (mile 87). The results indicate that these towns are sources of heavy pollution. Hinkston and Stoner Creeks are heavily polluted (septic) below Mt. Sterling and Paris (secondary treatment plant under construction 1939), respectively.

A study of the fishes of the Licking River was made by Welter.(4) He lists a total of 70 species, mostly minnows, shiners, catfish and suckers which are widely distributed in the upper region of the watershed. Various species of bass and sunfish are reported from the main stream at Farmers and Triplet, and from Fleming and Beaver Creeks.

Kentucky River

The Kentucky River rises in the mountainous region of the southeastern portion of Kentucky and flows in a general northwesterly direction to its junction with the Ohio River at Carrollton. The river is formed by the confluence of the Middle, North and South Forks near St. Helena, in Lee County. The three forks rise in Clay, Leslie and Letcher counties, respectively, which lie in the Cumberland Plateau near the Virginia border. The length of the main stream from Carrollton to the junction of the North and Middle Forks is 259 miles. The watershed area is 6,940 square miles. The average slope below Beattyville (mile 255) is about 0.9 feet per mile.

The Kentucky River headwaters are located in an important coal region. Many of the smaller tributaries are heavily polluted with acid drainage from coal mines, giving the water and bottoms of the streams a rusty appearance. This region is subject to heavy rains during the summer, and flash floods are commo

The river has carved a deep gorge of unusual beauty through limestone and shale for many miles of its course, forming the "Palisades of Kentucky" at High Bridge, 117 miles above Carrollton. The mountainous region gives way to beautiful rolling hills forming the well-known "Bluegrass" region around Lexington, through which the river meanders to the Ohio. The fertility of the soils is due to the phosphate nature of the limestone from which the soils are derived.

Population distribution is determined by the geological characteristics of the basin. There are many scattered towns of a few hundred inhabitants in the coal region, but the largest concentration of population is located in the Bluegrass region around Lexington which has a population of 49,304 (1940). Frankfort (pop. 11,492), the state capital, is located on the river, 66 miles above its mouth.

The Kentucky River has been improved for navigation by the construction of fourteen locks and dams from Carrollton to Beattyville.

A series of samples was taken at the mouth of the Kentucky River at Carrollton, from May 2 through November 30, 1939, (Figure 8 and Table 4). From June 9 through September 1, the river was in a very turbulent condition and only a few samples were taken. Following the first of September, the turbidity remained at a low level. The numbers of coliform organisms found at the sampling point were extremely low. The B.O.D. approached 3 p.p.m. before the turbidity increased in the late spring, and was in the neighborhood of 2 p.p.m. at certain times during the summer, showing no correlation with the numbers of the coliform organisms. It is interesting to note that considerable plankton was found in the stream even at times of rather high turbidity. There was a sharp peak of plankton about September 7, due, for the most part, to a bloom of large Pandorina which quickly disappeared. At the termination of this bloom the plankton sank to 0.05 M.p.p.m. or less and remained at this low level for the rest of the period of observation. The plankton curves give an impression that a limited amount of nutrient material was present and was exhausted by the bloom of Pandorina mentioned above.

The usual low level of dissolved oxygen during the hot summer months shows a rise at the time of the Pandorina bloom. There is another rise at the advent of lower temperatures which may be ascribed to the greater solubility of oxygen under these conditions.

Fig. 8

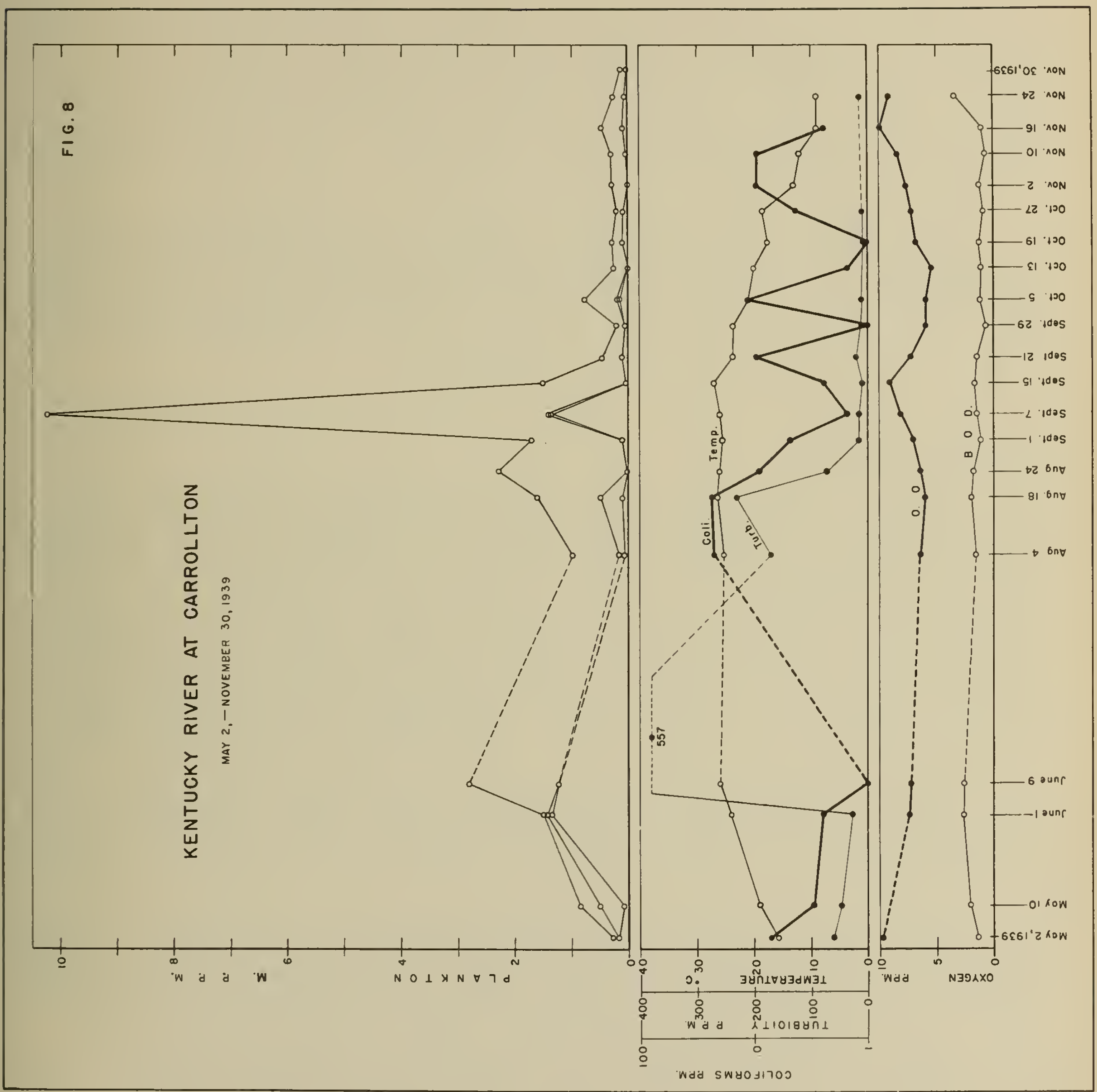


FIG. 8
KENTUCKY RIVER AT CARROLLTON
MAY 2, — NOVEMBER 30, 1939
PLANKTON
M. P. P. M.
TEMPERATURE °C.
TURBIDITY P.P.M.
COLIFORMS PPM.
OXYGEN PPM.
Temp.
Coli.
Turb.
557
O. D.
B. O. D.
May 2, 1939
May 10
June 1
June 9
Aug 4
Aug 18
Aug 24
Sept. 1
Sept. 7
Sept. 15
Sept 21
Sept. 29
Oct. 5
Oct. 13
Oct. 19
Oct. 27
Nov. 2
Nov. 10
Nov. 16
Nov. 24
Nov. 30, 1939

The Kentucky River shows an almost complete absence of Class II organisms, except for early spring, and shows an occasional flare of distoms. The characteristic features of the plankton in the Kentucky River involve the large numbers of certain Class I organisms which are found. Samples from the upper portion of the river, especially of the main branch, show extremely high numbers of Chrysophyceae, while samples from certain of the lower portions of the river (Frankfort and below) show large numbers of diatoms. With one or two local exceptions, Class II organisms are very scarce.

"Good Fishing" is reported locally on the Kentucky River from Carrollton to Gratz, and considerable commercial fishing is being done at Gratz, 29 miles above the mouth. Several species were reported, such as carp, catfish, pike, bass and perch. Local inhabitants reported that there are no game or food fishes in the river at Irvine (mile 218).

Big Sandy River

The Big Sandy is formed by the confluence of Levisa and Tug Forks at Louisa, 27 miles above the mouth. The main river and 94 miles of the Tug Fork form the boundary between Kentucky and West Virginia. The entire basin comprises an area of about 4,280 square miles, of which 2,280 are in Kentucky, 1,015 in Virginia, and 985 in West Virginia. The topography is largely mountainous or hilly, and the underlying rocks are composed of sandstone, shale and coal. There is considerable coal mining on the headwaters, and acid mine drainage and coal washings are important sources of pollution. The area was originally covered with hardwood forests, but most of them have been cut away. The soils are generally thin and infertile, and the slopes are too steep for successful agriculture. The small amount of good farming land is located along the streams and forms a very small percentage of the total area.

The average slope of the Big Sandy below Louisa is 1.1 feet per mile. The slope of Tug Fork is 12.2 feet per mile near the headwaters. The slope of Levisa Fork is about 1.3. The stream has been improved for navigation by the construction of three dams between the mouth and Louisa, and one dam on each fork.

The population of the Big Sandy Basin in 1940 was 411,905, of which 31,185 lived in towns of more than 2,500 people. About 35,000 lived in small incorporated towns, and a large but unknown number were in unincorporated mining camps. The density of population was 97 per square mile.

The important towns along the Tug Fork are Welch, population 6,264 (mile 160), and Williamson, population 8,366 (mile 84). The only town of urban size on Levisa Fork is Pikeville, population 4,185 (mile 115.7).

A series of samples was taken 0.3 miles above the mouth of the Big Sandy during the period from June 14 to November 27, 1939, (Figure 9 and Table 5). The B.O.D. at this location was less than 2.5 p.p.m. during the entire period of observation. The D.O. was fairly constant at about 6.5 p.p.m. following the middle of September, although during the time preceding this date there were some irregularities. During the period of decreasing temperatures, after the middle of October, there was a slight but constant rise in both the B.O.D. and the number of coliform organisms, which follows inversely the trend of the temperature.

There are several distinctive features of the plankton population at this location. There is an almost complete absence of diatoms, for the most part, and an unusually large and constant volume of Class II organisms. The low coliform organism counts are perhaps evidence of the relatively clean nature of the stream at the sampling point. This may be substantiated by the rise in plankton paralleling the rise in coliform organisms from September 1 to October 24. The depression in the plankton curve on October 12 is due to heavy rains which fell generally throughout the basin. The depression at the mouth on September 14 may perhaps be related to rains which fell at scattered points on September 5. There is a noticeable tendency for the plankton to survive after the B.O.D. and coliform organism values have dropped.

The deficiency of diatoms at this sampling point seems characteristic of the Big Sandy River as a whole, as data from points upstream seem to show. Diatoms are numerous only in that portion of the Tug Fork in the vicinity of Welch and Iaeger. The Big Sandy at the mouth receives wastes from a refinery a short distance upstream but this is apparently not the cause of the local absence of diatoms. Residents report that catfish and carp are present but that their flesh is unfit for food due to the odor and taste of the petroleum constituents.

Samples taken at points in the upper portion of the watershed show a predominance of Class I forms except immediately below sources of pollution.

Fig. 9

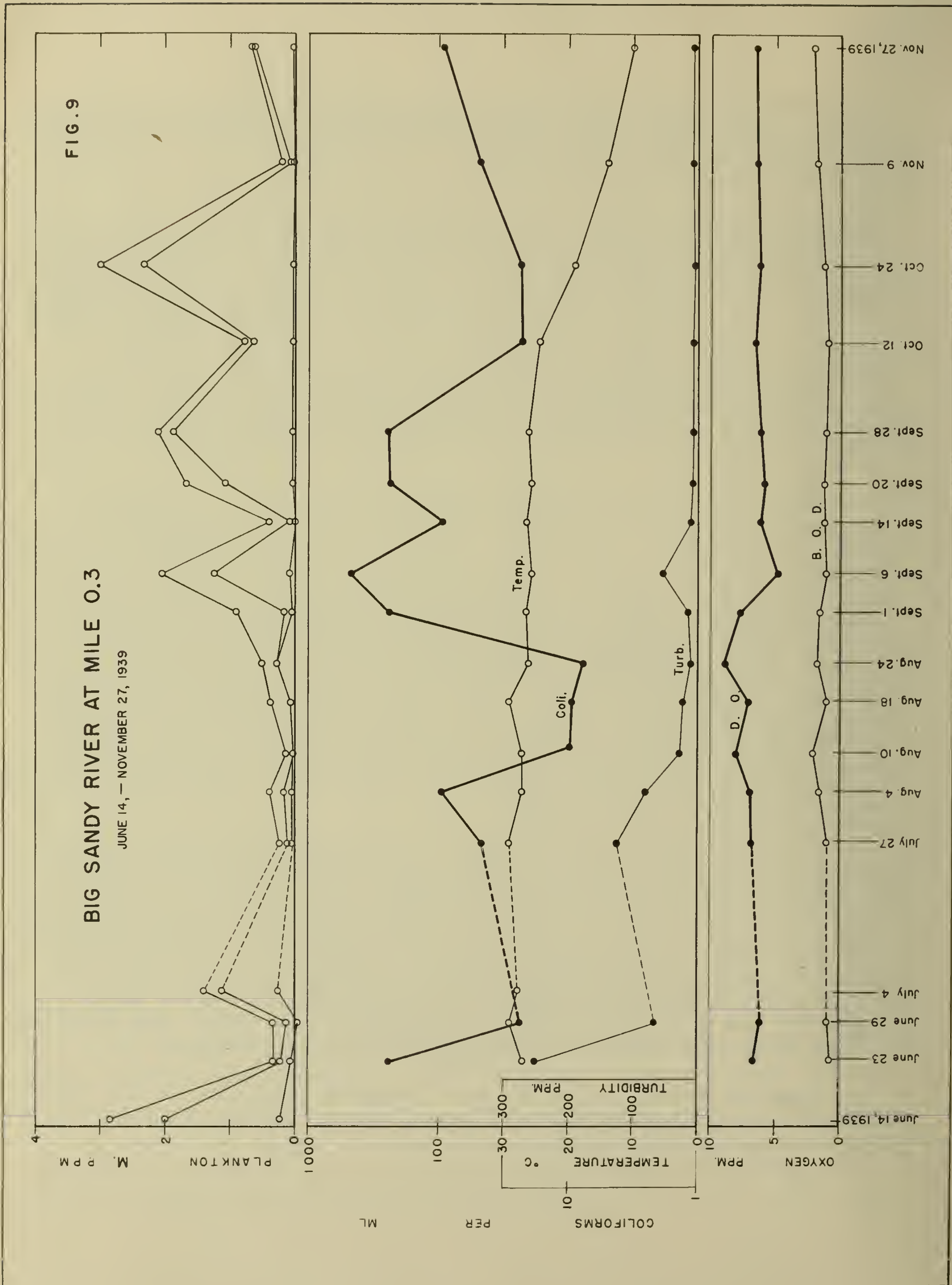


FIG. 9
BIG SANDY RIVER AT MILE 0.3
JUNE 14, — NOVEMBER 27, 1939
M. P P M
PLANKTON
COLIFORMS PER ML
TEMPERATURE °C.
TURBIDITY PPM.
OXYGEN PPM.
Temp.
Coli.
Turb.
D. O.
B. O. D.
June 14, 1939
June 23
June 29
July 4
July 27
Aug. 4
Aug. 10
Aug. 18
Aug. 24
Sept. 1
Sept. 6
Sept. 14
Sept. 20
Sept. 28
Oct. 12
Oct. 24
Nov. 9
Nov. 27, 1939

Little Sandy River

The Little Sandy River lies in the northeastern portion of Kentucky. It rises in the hills of Elliott County, and flows through steep, narrow valleys in a northeasterly direction. It joins the Ohio River below Greenup, Kentucky. Small coal mines are operated in the headwaters and a number of abandoned mines add acid drainage to many of the small tributaries. Sandy Hook (pop. 155), and Grayson (pop. 1,176), are the most important towns on the stream. There are, however, several communities between Sandy Hook and Grayson that empty untreated wastes directly into the river.

Samples were taken at the mouth of the Little Sandy River (mile 0.1) between June 14 and November 24, 1939, and a few were taken above and below Grayson (mile 28) in September, October and November (Figure 10 and Table 6). Until early in August, the water of Little Sandy was rather turbid and the B.O.D. and coliform organism values were low. It is during this period that most of the Class II organisms appeared in the plankton samples at the mouth of the river. Commencing with the sample of August 11, there is a rise in the general level of the coliform organisms and, to a lesser extent, of the B.O.D. In connection with these data for the mouth of the river, it is to be noted that samples in the region of Grayson on September 8 and 22 show fair numbers of Class II organisms below Grayson, in contrast to none above the town. Class I organisms, with the exception of *Cryptomonas erosa*, are scarce at the mouth of the river, while the samples in the vicinity of Grayson show considerable numbers of *Chrysococcus* and *Dinobryon*. As there is no consistent difference between the *Chrysococcus* population immediately above and below Grayson and as the stream is swift here, it seems that a certain distance is necessary for the effect of the pollution introduced by the community to be felt in the plankton population.

It is to be noted that in one sample, that of September 8, *Dinobryon* is present in considerable quantity below Grayson, while it is absent above the town. Aside from samples which include an occasional large ciliate, the plankton volume found at the mouth of the river was usually less than 0.5 M.p.p.m. The samples taken in the vicinity of Grayson were of the same order of magnitude.

Guyandot River

The Guyandot River rises in Wyoming County, southern West Virginia, and flows northwesterly, discharging into the Ohio River at Huntington, West Virginia. The length of the

Fig. 10

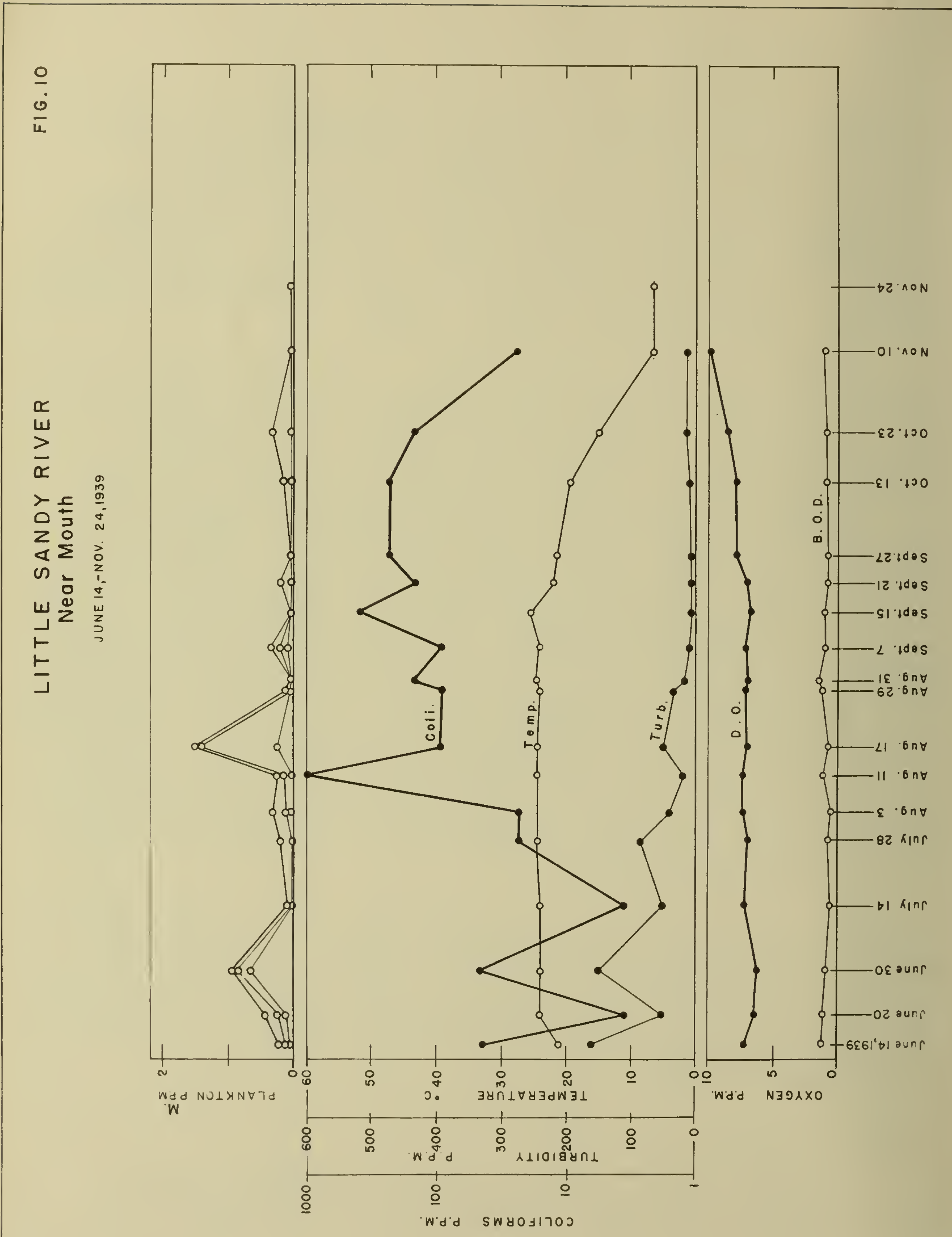


FIG. 10
LITTLE SANDY RIVER
Near Mouth
JUNE 14,-NOV. 24,1939
PLANKTON P.P.M.
M.
TEMPERATURE °C.
TURBIDITY P.P.M.
COLIFORMS P.P.M.
OXYGEN P.P.M.
Coli.
Temp.
Turb.
D. O.
B. O. D.
June 14,1939
June 20
June 30
July 14
July 28
Aug. 3
Aug. 11
Aug. 17
Aug. 29
Aug. 31
Sept. 7
Sept.15
Sept. 21
Sept.27
Oct. 13
Oct. 23
Nov. 10
Nov. 24

river is about 166 miles. The stream drains an area of 1,670 square miles of hilly and mountainous country between the Kanawha and Big Sandy Rivers. The area is underlaid by one of the largest bituminous coal deposits in the country. Natural gas occurs in the northern part of the basin.

Below Logan (mile 81), the stream has an average slope of about 1.8 feet per mile, while above Logan the slope averages 11.2 feet per mile. The flow of water is fairly uniform for the lower thirty miles, but above this the stream is a succession of pools and shoals.

The basin is a part of the Allegheny Plateau, and the poor soil and steep slopes make the land unsuitable for agriculture. Less than one-fourth of the land is cleared. The population of the Guyandot Basin in 1940 was 148,257. There are only ten incorporated towns in the basin and only two of these, Logan (pop. 5,166), and Mullens (pop. 3,020), has more than 2,500 people.

Samples were taken at irregular intervals at the mouth of the Guyandot River at Huntington (mile 0.6), from June 14 through November 27, 1939. The stream, at this point, is practically a pool from the backwater of Dam 28 in the Ohio River. At various times during the summer the water was colored by dye from an industrial plant in Huntington. A very heavy concentration of a blue dye appeared in a sample taken October 24, and the same dye appeared in the Ohio River sample taken below Greenup, Kentucky. It is difficult at the present time to state the effect of this dye upon plankton. The plankton volume was low during the period of observation. After August 14 it was less than 0.5 M.p.p.m. and usually less than 0.3 M.p.p.m. (Figure 11 and Table 7).

In contrast with the low plankton, the coliform organism count is extremely high and the B.O.D. also reaches high values. At times of high temperatures and high B.O.D., the dissolved oxygen is greatly reduced, reaching the low value of 0.08 p.p.m. on September 28.

The three peaks of the turbidity curve coincide with the three slight rises of the plankton curve and may indicate a flushing down of plankton from the higher, less polluted regions of the river. It should be pointed out that the B.O.D. does not reach the same relatively high values, for the most part, as the coliform organism count, indicating that it is possible to have domestic pollution of a type which constitutes a serious public health hazard without being indicated by a high B.O.D.

Fig. 11

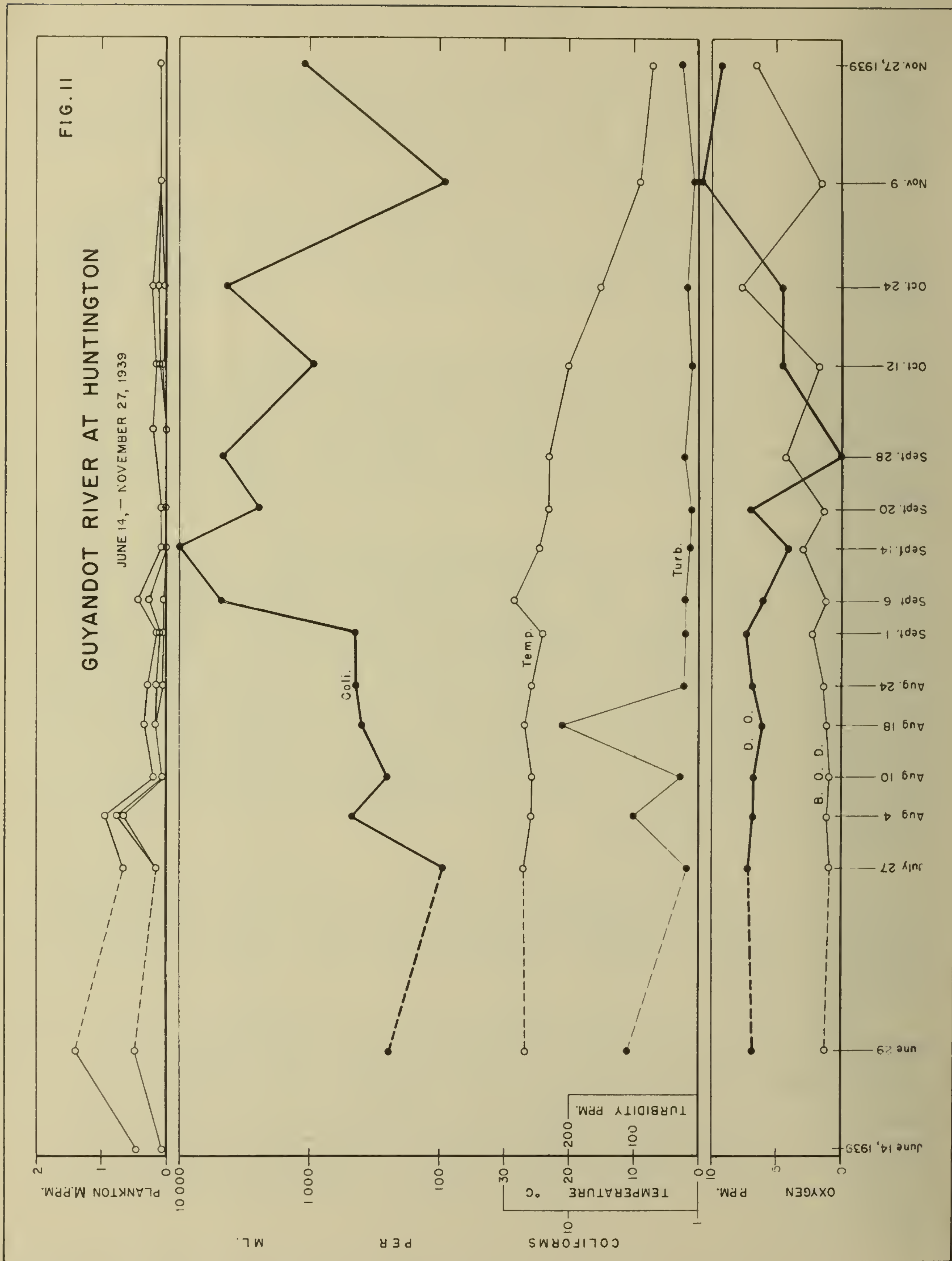


FIG. 11
GUYANDOT RIVER AT HUNTINGTON
JUNE 14, — NOVEMBER 27, 1939
PLANKTON M.PPM.
COLIFORMS PER ML.
TEMPERATURE °C
TURBIDITY PPM.
OXYGEN PPM.
Coli.
Temp.
Turb.
D. O.
B. O. D.
June 14, 1939
June 29
July 27
Aug 4
Aug 10
Aug 18
Aug. 24
Sept. 1
Sept. 6
Sept. 14
Sept. 20
Sept. 28
Oct. 12
Oct. 24
Nov. 9
Nov. 27, 1939

The stream between Huntington and Gilbert (mile 111.3) contains a high number of Chrysophyceae. There was practically no aquatic life in the stream at Pineville, Itman and Mullens, due to the heavy discharge from coal washeries. In October and November the water was black with small particles of coal. Likewise, the small tributaries in the headwaters, Buffalo, Island and Clear Forks, were devoid of life due to the discharge of coal mine drainage.

Kanawha River

The Kanawha River, with a drainage basin of 12,300 square miles, is formed by the union of the Gauley and New Rivers in the southwestern part of West Virginia and flows in a northwesterly direction, emptying into the Ohio River at Point Pleasant, West Virginia. The total length from the mouth to the junction of the New and Gauley Rivers is about 97 miles. The average slope of the upper portion is about 2 feet per mile, decreasing to 0.37 feet per mile at the mouth. Navigation has been improved for 90 miles by the construction of three locks and dams.

The upper three-fourths of the basin lies in mountainous territory, and less than one-twelfth of the entire basin is tillable. The total population of the basin is 834,845 (1940). Natural resources in the form of bituminous coal, oil and natural gas, have attracted a number of chemical plants to the Kanawha valley and the area is becoming one of the important chemical producing centers in the country.

The principal tributaries are the New, Gauley and Elk Rivers. The Elk is highly polluted by oil refineries and gas plants.

Scattered samples taken at Point Pleasant on the Kanawha River (mile 0.6) from August through November, 1939, show an exceptionally low coliform organism count and very low B.O.D., indicating that the stream at this point is undoubtedly quite clean (Table 8). This is confirmed by the absence of Class II organisms. The total plankton population is also low, although the sample of August 10 showed very large numbers of Cryptomonas, which persisted to a lesser extent in later samples. Chrysococcus was relatively scarce.

Samples throughout the month of July at scattered points up the river as far as Montgomery (mile 85) show a somewhat higher plankton volume, with occasional Class II organisms ap-

pearing. _Cryptomonas_ was high for some thirty miles or more up the river during this period. In October, samples from points in the headwaters of the river showed very little plankton, mostly _Cryptomonas_, _Chrysococcus_ and _Chlamydomonas_.

Upper Third

Monongahela River

The Monongahela River is formed by the junction of the West Fork and Tygart Rivers about one mile south of Fairmont, West Virginia. It flows through Pennsylvania, uniting with the Allegheny River at Pittsburgh to form the Ohio River. Its length is about 128 miles and it drains an area of 7,380 square miles. The average slope in the upper part is 2.1 feet per mile, which later drops to about 0.7 feet per mile. Fourteen locks and dams have been constructed along the river.

The Monongahela River is subject to an enormous amount of industrial pollution. A great portion of this pollution is acid waste of one type or another. During the latter part of June, 1940, while the water was still fairly high and rains were frequent, the acidity of the stream in the fifty-mile region between Morgantown (mile 100.9) and Roscoe (mile 48.5) hovered in the vicinity of pH 6. On either side of this intermediate region, the pH fell off rapidly, being approximately 3.7 at Pittsburgh (mile 0) and at Worthington on West Fork (mile 136). During this period the D.O. was fairly high. Plankton and chemical samples were available for August 19 from Dam 8 at mile 90 down to Dam 2 at mile 9 (Table 9). At this time the pH of the whole 80 miles lay between 3.3 and 3.7. Coliform organisms were practically absent and the B.O.D. was about 0.65 p.p.m. or less. The plankton volume was low and consisted almost exclusively of _Closteriopsis_. A few diatoms were found locally. Plankton samples taken late in June showed many _Navicula_, some _Cymbella_, _Dinobryon_, and some unidentifiable green flagellates in the vicinity of Morgantown.

Fish studies were made during the latter part of June and the first part of July. In the upper region, on the West Fork of the river, at Good Hope, W. Va., there is a fair fish population, consisting of long-eared sunfish, smallmouth bass, redhorse suckers and rock bass, together with a rather large number of various shiners and minnows. Only one shiner each was found at Rivesville and Worthington. From there (mile 136) to the mouth of the Monongahela, only an occasional fish (shiner) was collected, except near the mouth of a nonacid tributary. Many of these nonacid tributaries contribute a good mixed fish fauna, but the fish apparently do not become estab-

lished in the Monongahela. Many catfish, carp and suckers, as well as some of the game fish, were found dead or dying below the entrances of such tributaries.

No fish, with the exception of one small sunfish and one small catfish, were taken on the Tygart below Grafton Reservoir, although the state had stocked the reservoir with game fishes.

Allegheny River

The Allegheny River has its source in north-central Pennsylvania. It flows in a northwestern direction into the state of New York, turns and flows back into Pennsylvania. From here its course is southwest to Pittsburgh, where it unites with the Monongahela River to form the Ohio. Its length is about 325 miles. The average slope below Olean, New York, (mile 259), is 2.7 feet per mile. The drainage area is about 11,730 square miles, of which 9,775 are in Pennsylvania and 1,955 are in New York. This area lies in the Appalachian Plateau and is, for the most part, hilly or mountainous. The river has been improved for navigation by the construction of eight locks and dams, to mile 61. The population of the basin (1940), exclusive of the City of Pittsburgh, is approximately 1,237,000. The distribution between urban and rural population, also exclusive of Pittsburgh, is 42 per cent and 58 per cent, respectively. The population (1940) of Pittsburgh is 671,659, of which slightly over one-third is in the Allegheny River Basin.

In contrast to the Monongahela River, the Allegheny, above mile 50, shows a pH 7 or higher. Below this point a certain amount of acid pollution occurs.

Samples were taken of the main stream during the month of August, 1940, (Table 10). Following downstream, the Tionesta River (mile 154) seems to be the source of the first heavy pollution. From the chemical data, there would seem to be some acid pollution as well as an introduction of organic material. The D.O. drops sharply to about 5 p.p.m. The reserve alkalinity drops and the pH is about 7.4. These effects may be due to a tannery located on the Tionesta.

There is a plankton population below the Tionesta of about 1.5 p.p.m. Diatoms are plentiful and Class II organisms are infrequent. From Kennerdale (mile 110) down, the plankton is composed almost entirely of Class I organisms, especially diatoms.

The irregularities of the plankton volume figures are accentuated by numbers of the large diatom Surirella at miles 14, 50 and 70. It is striking that at Brackenridge (mile 22) no plankton whatever was found. B.O.D. values of about 1 p.p.m. in this region of the stream above mile 50 are, in general, higher than in the acid stream below. At Pittsburgh a large number of coliform organisms are introduced into the river with a relatively slight change in the B.O.D.

The Allegheny River, from the headwaters to Kittanning (mile 46), supports a fair mixed fish population. Various suckers, crappies, bass and sunfish were collected at Warren, Pennsylvania. Further down the stream at East Brady, bass, hogmolly and quillback suckers were taken. At Mosgrove, suckers, walleyed pike, trout-perch and smallmouth bass were fairly abundant.

The Clarion River supports a large fish population consisting of yellow perch, small- and largemouth bass, rock bass, catfish, suckers, carp and numerous snapping turtles. This stream is colored black from tannery and paper mill wastes in the headwaters. Fish caught in this stream could not be used as food, as their flesh was tainted from the chemicals. The Tionesta, also polluted by paper and tannery wastes, supports a large fish population. Many of the streams tributary to the Clarion and the Tionesta contain trout, but no trout were taken in the main stream. The Kiskiminitas River is too acid from mine drainage to support fish.

Muskingum River

The Muskingum River is formed by the confluence of the Walhonding and Tuscarawas Rivers at Coshocton, Ohio. It flows in a southeasterly direction and empties into the Ohio River at Marietta. Its length is about 110 miles and average slope 1.5 feet per mile. The Muskingum drains an area of 8,040 square miles, comprising about twenty per cent of the entire state of Ohio. The northern and western portions of the basin have been smoothed by glacial action, and the topography is undulating to rolling. Seventy to eighty per cent of the basin is used for agriculture. The rate of flow is controlled by reservoirs in the upper part of the watershed. Eleven locks and dams have been constructed to a distance of 91 miles from the mouth of the river.

The total population of the basin in 1940 was 812,028, about equally distributed between urban and rural inhabitants.

The leading industries are steel, metal products, clay, rubber and paper. Coal is mined to a limited extent in the eastern part of the basin.

The data for the Muskingum River are particularly unsatisfactory as this watershed was subjected to rains during most of the period of study. As a result, plankton samples are scattered in date between the beginning of April and the end of August, 1940. It is unfortunate that the one good series of plankton samples taken on July 19 is unaccompanied by any chemical data. The April samples show diatoms almost exclusively, although the plankton volume is low. These conditions still exist at the mouth of the river early in June. Below Zanesville (mile 75) at this time there is a considerable volume of plankton containing an occasional Euglena or Protozoan but still composed, to a large extent, of diatoms. In July the plankton was somewhat more varied, while in August a samplg taken above McConnelsville (mile 48) at Duncan Falls (mile 66.8) showed the plankton well distributed among the different taxonomic groups.

The series of July 19 was taken from Zanesville to below Stockport (mile 39) and indicates the following influences (Table 11). The plankton volume is quite high in the region below Zanesville, dropping somewhat as one approaches Duncan Falls. At Duncan Falls the volume again increases sharply, with an increase in the number of Class II organisms. From Duncan Falls through Gayport and McConnelsville, the volume drops off somewhat, although still maintaining high levels, and a further drop occurs below Stockport. The plateau between Gayport and McConnelsville may be due to an absence of intermediate samples. The watershed supports a good mixed fish population.

Hocking River

The Hocking River, having its source about 35 miles southeast of Columbus, Ohio, empties into the Ohio River at Hockingport, Ohio. Its length is about 100 miles. The average slope above Lancaster (mile 89) is 4.5 feet per mile, and the lower part of this river has a slope of 2.3 feet per mile.

The Hocking River drains an area comprising 1,185 square miles. The population of the basin in 1940 was 113,555. A little more than half the population is urban. The natural resources of this area are coal, clay, natural gas and oil, and farming is the principal industry.

Scattered samples were taken at various points on the Hocking River in late May, June, July and August, 1940. In May,

samples taken at Coolville (mile 5) and Guysville (mile 20) showed a plankton largely composed of diatoms, with some Cryptomonas, Chrysococcus, Dinobryon, and an occasional ciliate or Euglena. The most abundant organism was Navicula, a diatom. The plankton at Coolville was rather more abundant than at Guysville.

A sample taken below Athens (mile 35) in late June showed a varied plankton population with considerable numbers of Class II organisms. The plankton at Hockingport (mile 0.1) at the same period was somewhat less abundant and contained fewer Class II organisms and more Class I forms. In July the plankton of the lower river was quite abundant and varied. There were considerable numbers of Class II as well as Class I organisms at Hockingport, Coolville and Guysville. There was little plankton at Nelsonville (mile 53), while the plankton above Logan (mile 67) consisted mainly of diatoms, with some Euglena. Below Sunday Creek (mile 42) the plankton was much reduced, both in kind and number. The most common forms were the diatom, Asterionella, and Oscillatoria, a blue-green alga.

In August a fairly complete series was obtained from below Nelsonville to Hockingport (Table 12). The D.O. during this period was fairly good, with a depression in the values below Athens. The plankton was fairly abundant below Nelsonville, being composed largely of Class II organisms. Between Nelsonville and the region above Athens the plankton volume was sharply decreased. This was undoubtedly due to the influence of Sunday and Monday Creeks, which were pouring water of approximately pH 3 into the main river. A resurgence of the plankton occurs from Athens to Guysville. The depression at Coolville cannot be well explained except as indicating the absence of an immediate source of pollution. At Hockingport the plankton volume was again high, passing 6 M.p.p.m.

Fish collections made during this August trip showed that smallmouth bass were plentiful below Nelsonville and that biological conditions in general seemed good. Hogmolly and shiners of all sizes were present, crayfish were plentiful, and there were many empty mussel shells. However, there was a whitish growth noticeable on the bottom and on the rocks. Above Athens, below the entrance of Sunday and Monday Creeks, fish were less plentiful. Minnows were numerous but bass were found in much smaller numbers and hogmollies were replaced by quillback suckers. The bottom of the stream was of a greenish-black color.

At Coolville fish seemed quite abundant. Many people were fishing on and alongside the dam. The seine caught numerous

small catfish, common and quillback suckers, smallmouth bass and hogmollies. In general, these fish were larger than those caught upstream.

Little Kanawha River

The Little Kanawha River rises in the western foothills of the Allegheny Mountains, near the eastern border of West Virginia, and flows north about 160 miles, emptying into the Ohio River at Parkersburg, W. Va. The average slope below Burnsville (mile 122) is about 1.5 feet per mile. The river drains an area of 2,320 square miles.

The basin has been cleared of forests, except above Burnsville, and is devoted to agriculture. Oil and gas fields are located over a considerable portion of this area. There are also local coal deposits in the region of the headwaters. With the exception of oil and gas, there is little industrial development in this basin. The population in 1940 was 92,355, almost entirely rural.

A series of samples was taken along the Little Kanawha River from Glenville (mile 103) to its mouth, late in August, 1940, (Table 13). The plankton at Lock 3 (mile 25) and above is rather low for the most part. The high volumes appearing in the table at miles 28, 80, 101 and 103, are each due to one or two specimens of large diatoms which affect the volume figures considerably.

Creston (mile 48) and Elizabeth (mile 27) seem to be the principal sources of pollution along the upper stream. Below Elizabeth the Hughes River enters at mile 17 and carries only a small volume of plankton. The upper Little Kanawha River has the local reputation of being the best bass water in the state. The stream, at the time of investigation, was low and the volume of water small. Seining conditions on the whole were bad. Net catches consisted mainly of common and redhorse suckers, turtles, and an occasional Kentucky bass. At Creston, where the West Fork enters, fish were relatively plentiful, suckers of various kinds and a few smallmouth bass being noted. The West Fork has a reputation as a good pike stream, having some deep holes from which large fish are occasionally caught. Below Elizabeth, catches consisted of small suckers, sheepshead, mooneyes, crappies and white bass. Seining conditions were unfavorable.

At the time of our visit in August, peculiar conditions were found at the mouth of the river from Dam 1 (mile 4) to the

Ohio. The water was highly turbid and opaque, and there was considerable scum on top. The water coming from the pool above made a distinctly marked area of cleaner water below the dam. In this region fish were actively breaking water, while further below the scum was unbroken. At the East Parkersburg Bridge, the same general conditions prevailed, except that no fish were seen. D.O. determinations showed 0.33 p.p.m. of oxygen at the bridge. Immediately above the dam the oxygen value was 5.9 p.p.m., while at the lower end of the lock wall, in the scum-covered region, the oxygen was 3.3 p.p.m. There were, furthermore, distinct temperature and pH differences between the water above and below the dam, both the acidity and temperature being higher below the dam.

The plankton on this date showed a large bloom of Pandorina above the dam and extending into the pool below. The numbers of Pandorina at the East Bridge were considerably lower, although still high. These organisms formed the bulk of the plankton population.

According to observers, fish had been dying in the pool for several weeks. Evidence of this was found below the dam where numbers of dead fish were floating and stranded on the shore. These included bass, suckers, mooneyes, shiners, sunfish, crappies, some very large pike, and other large fish no longer identifiable, as well as salamanders and other water creatures, but notably few catfish were found. According to the lockmaster, this fish slaughter has occurred every year under similar weather and low water conditions. In years when a temporary rise occurred in the middle of the season, there would be a recurrence of fish deaths as the water again subsided. Under these lethal conditions the water becomes unfit even for industrial use by the large Viscose plant located at Parkersburg. This plant has an accessory water intake above the dam for use during these periods.

As stated above, very few catfish were found among the material stranded on the bank. However, on August 23, at the East Bridge, it was noted that large numbers of black catfish were seen along the surface of the river, moving very little but occasionally struggling or disappearing temporarily from the surface of the water. It proved possible to catch some of the fish from the shore by means of a dip net. The fish would swim slowly along the surface and go directly into the net without any effort to escape. An occasional very small fish, other than catfish, was seen along the shore, which was apparently able to survive the water conditions temporarily. Measurements showed that there was zero oxygen concentration in the water at that point.

Measurements in the vicinity of the dam showed that the oxygen values had fallen at this point also, being approximately 4.7 p.p.m. above the dam and 2.3 p.p.m. below the dam. The temperature and pH differences between the two sides of the dam still existed. The plankton distribution had changed overnight. The number of Pandorina above the dam had dropped, while below the dam it had risen appreciably. This seemed to indicate that there had been a wave of these organisms which had passed over the dam.

Pandorina "blooms" have been found at other times and places and, in general, the evidence is that these blooms raise rather than lower the D.O. In no case have they been found toxic to aquatic life. It is, therefore, clear that the conditions at Parkersburg cannot be blamed on this organism. In view of the circumstances and the general condition of the river at this point, it seems clear that some relation exists between the low D.O. values, which presumably have been causing fish deaths, and local industrial plant operations. The details of this must, of course, be investigated in order to determine exactly what is responsible for this slaughter. The most likely presumption is that some carbohydrate industrial effluent, under high temperature and low water conditions, furnishes the substrate for heavy bacterial growth with the resultant exhaustion of the oxygen supply.

Lower Third

Wabash River

The Wabash River rises in Mercer County, Ohio, and flows across Indiana to Covington, before turning south to join the Ohio River about ten miles above Shawneetown, Illinois. This basin covers most of the state of Indiana and a large section of Illinois. The total area of the basin is 33,100 square miles, 320 square miles or 1 per cent of which is in Ohio, 24,220 square miles or 73 per cent in Indiana, and 8,560 square miles or 26 per cent in Illinois. Included in this area are the tributary basins of the White River, the Embarrass River, the Vermilion and Little Vermilion Rivers, the Little Wabash, Eel, Mississinewa, Patoka and Tippecanoe Rivers. The length of the Wabash River is about 475 miles. The average slope below Lafayette (mile 311.7) is about 0.6 feet per mile.

The population of the basin in 1940 was 2,508,598, divided about equally between rural and urban dwellers. Indianapolis, situated on the White River, with a population of 386,972, is the largest city in the basin.

The leading industries are manufacture of steel, paper, textiles, leather, machinery and transportation equipment. A small amount of coal is strip mined in the western part of the basin. A large portion of the building limestone of the country is produced around Bloomington. Oil production in eastern Illinois, near New Harmony, Indiana, is increasing.

The plankton samples for the Wabash River were taken during August, September and October, 1940, with the majority of the samples taken in September. Rain occurred in the Indiana region at the end of August, and September 10 and 25. The September rains were generally light and did not appreciably affect stream conditions, except for the samples taken during the rain. Because of the time-spread of the samples, it is not possible to present the results of this study in a single continuous curve. It will be necessary, therefore, to discuss the findings with some regard to the time sequence.

One of the characteristic organisms of the Wabash River and also of the White River, is a Stephanodiscus which appears frequently and in large numbers. The combination of size and number exerts a great effect upon the plankton volume figures. In August this organism was found localized in the upper portion of the river, above Logansport (mile 355). Later in the month numbers were also found at Pittsburg (mile 331) and Hillsdale (mile 238). Rains occurred throughout the watershed the last days of August and may have been instrumental in the new distribution found in the first few days of September. At this latter time the diatom was almost totally absent above Logansport, but was found in numbers from Logansport to the vicinity of Lafayette. Toward the end of September and early in October, its population center above Logansport was again established, though the organism could also be found at Georgetown (mile 347).

In addition to this factor in the volume values, there must be noted the usual seasonal fluctuations of the relative numbers and distribution of the plankton (Table 14). It should be borne in mind that the Wabash River has no dams to cause a pooled condition of the river during the summer low water period. The flow is, therefore, somewhat swifter than in a dammed stream. In general, as the summer season advances and the river level drops, it will be found that the plankton volume drops and the proportion of Class II organisms increases immediately below the source of pollution. Examples of this are found in the region below Terre Haute, Perrysville, Logansport, Peru, and other major points of pollution. This may be ascribed to the sequence of the processes of decomposition of organic pollutants outlined above.

Conversely, at points further downstream, below these same sources of pollution, the proportion of Class II organisms may decrease, due to the upstream completion of the disintegration process under higher temperatures and reduced stream flows.

At the end of September, and the beginning of October, when low temperatures start to appear in this basin, the plankton is found to decrease sharply and the Class II organisms and certain of the Intermediate group become diminished in number, or are totally absent. This parallels the findings in other basins.

Judged by the plankton volumes, certain of the towns along the upper river are important sources of pollution. This is readily checked by casual visual survey of the regions involved. Peru, for example, for a short distance below the outlet of its sewage treatment plant, produces a heavy algal growth along the river, which in this region is rather shallow. This characteristic of the river bed becomes further accentuated nearer Logansport. Above Logansport, the stream appears rather clean. Commencing at the outfall of the upper sewers, there is found a region of intense pollution, which exists downstream for a considerable distance. During the summer season the stream at this point is shallow and rocky, so that considerable pooling results and numerous narrow channels are formed. The bottoms and sides of the channels are covered with a growth of attached Protozoa and other organisms common to extremely polluted regions. Further downstream, the growth of algae is very heavy and the various odors are unmistakable. It is probable that under conditions of high stream flow the sewage introduced at this point is carried for a considerable distance downstream.

The peak of the plankton, due to Logansport pollution probably, occurs in the region of Delphi, some twenty-odd miles downstream. From Delphi the volume of organisms drops off until the influence of the Lafayette effluent is felt in the vicinity of Independence (mile 294). At times of high water the peak may occur further downstream.

Terre Haute (mile 215) is a source of heavy pollution to the Wabash River. In addition to the untreated domestic waste of its residents, a number of commercial plants along the stream introduce their wastes into the river. At this point the current is fairly swift so that the waste materials are distributed for a considerable distance downstream. Nevertheless, the combination of sewage and industrial wastes introduced at this point results in a D.O. of less than 4 p.p.m. and high coliform organism and B.O.D. values for some 35 miles downstream. Due to the swift current and distribution of the

pollution over a considerable length of the river, the fertilization effect on the plankton is not localized to the point of producing a prominent peak such as is found under certain other conditions. Such peak as there is seems to occur far downstream at Meron Ferry (mile 165). Both magnitude and location of the peak are variable.

From Meron Ferry downstream the plankton volume gradually falls off. There is a slight peak at Patton (mile 102), and from a point below Mt. Carmel (mile 95, below the mouths of the White and Patoka Rivers) there is a slight rise in the plankton volume as the mouth of the river is approached. This may be due to a combination of additional pollution from towns along the river and the influence of the dams on the Ohio River in slowing up the flow at the mouth of the Wabash. This allows time for the organic material to decompose to available food and for the plankton organisms to multiply.

The Wabash River on the whole has a good fish fauna. Certain of its tributaries have the reputation of being excellent game fish streams. Among these may be included the Mississinewa, Tippecanoe and Eel Rivers. Wildcat Creek, which enters above Delphi, is also rich in game fish. Above Peru, the Wabash River contained smallmouth bass, crappies, sunfish, mooneyes and shiners. The crayfish found in this location were clean and brightly colored, similar to those in the Mississinewa River, which enters close by. Below the Peru sewage plant, where the water supported a heavy growth of algae, gar pike, common suckers, several smallmouth bass, smallmouth buffalo, mooneyes, sunfish and shiners were present. Above Logansport, in addition to gar pike, common suckers and smallmouth bass, a number of channel catfish were present. Sunfish and shiners were also abundant. Large fish were seen breaking water further out in the stream. Many snails were present in this region.

Below Logansport, in obviously foul water with heavy sludge and marginal algal growth, fish were relatively scarce; several suckers, sunfish and shiners constituted the catch. At Delphi, fish were plentiful and varied. Smallmouth and white bass were caught, and common and redhorse suckers were large. Mooneyes were also of large size, both yellow and channel catfish were found, and long-eared sunfish, shiners and darters all seemed well-fed.

Above Lafayette, smallmouth bass seemed common, while sunfish, shiners and darters were quite plentiful, in spite of poor seining conditions. Below Lafayette, bass were absent but gar pike, channel catfish, mudcats, shiners, darters and sunfish were plentiful. The marginal algae were very abundant.

The river bottom consisted of shifting sand. At Covington, the fish species again became numerous and varied. White bass and large- and smallmouth bass were present, as well as mudcats and bullheads, quillback suckers, sunfish, shiners and gar pike. The bottom of the river was muddy in this region.

At Montezuma several white bass were taken, while both mud and channel catfish were very numerous, but small. Sunfish and minnows were plentiful, and quillback suckers were also caught. Natives report buffalo and suckers present. A short distance above Terre Haute the seine captured largemouth bass, common suckers, channel catfish, mooneyes and shiners. Quillback suckers were extremely numerous at this point. White bass were reported to be present.

In contrast to upstream conditions, below Terre Haute, where the stream was narrow and swift, with a clean, rocky bottom, no fish at all were taken and only two sick crayfish were found. The water was noticeably bad; garbage, algae, paper, fiber mill wastes and other debris could be seen floating in the stream.

Ten miles below Terre Haute natives reported fish to be absent; confirmatory seining was not attempted. The D.O. at this point was still below 4 p.p.m. At Meron Ferry, quillback suckers were very numerous, with sunfish, mooneyes and shiners also present. A recently dead sturgeon was found floating, and the remains of buffalo and crappies were found on the shore. Local fishermen were seen with catches of black bullheads. The natives report that bass were once plentiful at this point but are now absent.

Below Vincennes, sunfish and shiners were very abundant with an occasional small mudcat and darter. At this point there was considerable growth of algae along the shore and on the bottom of the stream. At St.Francisville, numbers of quillback suckers, shiners, chubs and some mooneyes were again collected. There was a very noticeable tendency on the part of the quillback suckers to restrict themselves to that portion of the bottom covered with algae and to be almost totally absent from the uncovered area.

Below Mt.Carmel and the mouths of the tributaries at that point, fish were varied. Large- and smallmouth black bass, sunfish, channel and mud catfish, quillback suckers and shiners were caught, as well as gar pike. Live mussels were seen, but there were no crayfish. The bottom was sandy.

At Grayville, Illinois, (mile 61), largemouth (Kentucky?) bass were plentiful, and white bass were extremely numerous. Shiners, sheepshead, quillback suckers, mooneyes, gar pike and channel catfish were found. Commercial fishermen showed large buffalo and quillback suckers, channel cats and eels. They claimed that carp and other types of fish were also present. Below New Harmony, channel catfish, largemouth bass and white bass were noted, but the principal fish present were sheepshead, quillback suckers and shiners.

Upper Tributaries - The Mississinewa River, which enters the Wabash 375 miles above its mouth and a short distance above Peru, was quite clean and contained less than 0.5 M.p.p.m. plankton. The Eel River enters the Wabash 354 miles above its mouth, at Logansport. This is considered to be a clean stream and is used for the townwater supply. At the sampling point near the intake of the city water supply, over 11 M.p.p.m. of plankton were found, consisting mainly of the diatom, Stephanodiscus. However, there were close to 0.2 M.p.p.m. of Class II organisms. Observations seemed to indicate that this was a favorite spot for horse-washing, as these animals were led into the stream and cleaned at this spot.

Wildcat Creek, entering the Wabash River at mile 317 near Delphi, contained over 2.5 M.p.p.m. of plankton, principally Intermediate forms. Many small- and largemouth bass were found here. Common, quillback and hogmolly suckers were caught. Sunfish, crappies, bluegills, mudcats, shiners and darters were plentiful. Large gar pike and walleyed pike were reported present by local residents.

Tippecanoe River (mile 322). The water of the Tippecanoe River is very clear. The river itself has a larger bottom growth of the higher aquatic plants than was usual in the Wabash watershed. Samples were taken in the river, and the two lakes which form a part of it, about September 7. Plankton was found to be less than 0.7 M.p.p.m. at all stations, although ten days earlier it had been as high as 5 M.p.p.m. at one of the lakes and 1.8 M.p.p.m. at the lowest sampling point. A certain number of Class II organisms were present in the upper reaches of the river and in the lakes. At Springboro, above the mouth of the stream, these were absent, although a few filaments of Sphaerotilus were found. The number of Class I organisms was somewhat higher at this point.

At Springboro, a number of smallmouth bass, hogmollies, shiners and darters were found. Larger specimens of these spe-

cies, as well as common suckers, could be observed in the clear water from the bridge over the stream. The river is apparently a popular fishing stream and the lakes are widely used as summer resorts.

Vermilion River (mile 257) - The Vermilion River was studied in the region of Danville, Illinois, not far above its mouth. Above Danville stream conditions were fairly good. The D.O. was approximately 9 p.p.m. and the total plankton less than 1.5 M.p.p.m.

Following the stream through the town reveals a drop in dissolved oxygen and an increase in the algal growth. Below town, about one hundred yards above the entrance of the sewage plant effluent, the D.O. was 3.5 p.p.m. and a few sunfish, minnows and small black bass were noted. These were not in prime condition. Floating masses of blue-green algae were seen and the total plankton volume was about 5 M.p.p.m., of which about 3.25 M.p.p.m. consisted of Class II organisms.

About one mile below the sewage plant the D.O. was 1.87 to 2.05 M.p.p.m., and the total plankton varied between 6.5 and 9 M.p.p.m. on successive days. Class II organisms composed over two-thirds of the plankton. The water was obviously polluted and there was considerable sludge on the bottom. Several sunfish and two small German carp were caught, even though the D.O. value was below 2 p.p.m. About five miles downstream, conditions improved somewhat, the D.O. rising to about 5.5 p.p.m. Fish were numerous. Many largemouth bass, a small number of smallmouth bass, sunfish, yellow catfish, spotted darters, log-perch, quillback and common suckers, shiners and carp were caught. However, a large number of the fish were sickly, abnormal or parasitized. The bottom was still noticeably muddy. The total plankton had dropped to 3 M.p.p.m. at this point and the volume of Class II organisms was about 0.5 M.p.p.m.

At the time of sampling, the plant effluent was approximately 1/28 of the total stream flow.

Embarrass River (mile 122) - The Embarrass River, above Lawrenceville, Illinois, in the middle of September, 1940, had a plankton population of 5.9 M.p.p.m., due to a large number of the diatom, Pleurosigma. Some Class II organisms were present. Two weeks earlier the Pleurosigma and Class II organisms were both much more abundant. Several miles below Lawrenceville, at Billet, the volume of Class II organisms increased to 0.8 M.p.p.m. and the total plankton was 0.9 M.p.p.m. Above Lawrenceville, largemouth bass were extremely numerous and many quillback suckers were caught. There were some minnows, long-

eared sunfish and gar pike. A carp weighing 7.5 pounds was also caught. The stream was not very wide at this point, but there were apparently some deep holes. Dissolved oxygen was 8.7 p.p.m. At the sampling point below Lawrenceville, oxygen was close to 9 p.p.m., but no fish or crayfish of any kind could be found. There was a scum of oil covering a portion of the water, and algae were floating and on the bottom. The bottom itself was an oily mud. No insects could be seen, and the water was fairly clear.

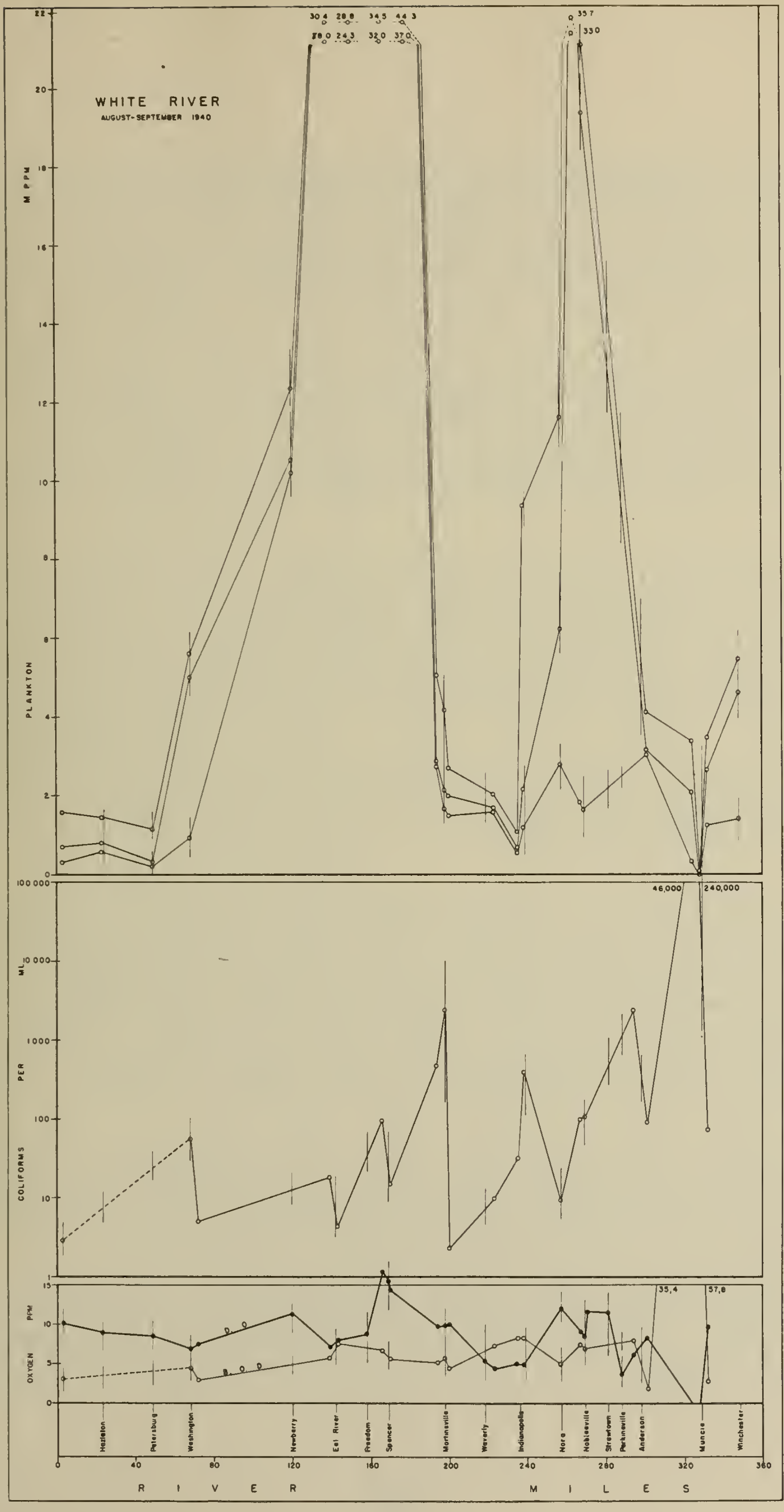
Little Wabash River (mile 15) - The rate of flow was very low in the Little Wabash River (late September). At Carmi, Illinois, the water was quite stagnant, with a heavy growth of algae covering the surface. The D.O. was high and approximated 12 p.p.m. The plankton found consisted mostly of Class I organisms.

Below Emma, Illinois, deep, quiet pools occur, in which the water was quite stagnant and green. Fish were occasionally seen to break water. The plankton here was approximately 6 M.p.p.m., with over twenty per cent of this being composed of Class II organisms.

White River (mile 96) - The majority of samples from the White River were taken in the latter half of September. Three or four samples were taken in the third week of August. Samples from a given region were taken at the same period so that consecutive points in the region of a source of pollution are comparable.

As the studies of other rivers have shown, the month of September is one of stable conditions, during which light rains exert little, if any, influence upon the stream plankton. For this reason and because of the general agreement between the values at different points, Figure 12 may be taken as representative of the September conditions on this stream.

The White River is subject to heavy pollution for almost its entire course (Table 14). Our observations started at Winchester (mile 338) and Muncie (mile 309) where samples were taken in August. The pollution immediately below Muncie, as indicated by the B.O.D. and coliform organism values, is so intense that the plankton population is almost entirely destroyed. It is possible that some ciliates exist under these conditions, that, for various reasons, did not show up in the plankton samples. The recovery below Muncie is rapid but the plankton volume reaches its peak in the region above Noblesville (mile 265) where a tremendous growth of Class II organisms was found. A large part of this growth consisted of


WHITE RIVER
AUGUST-SEPTEMBER 1940
PLANKTON M PPM
COLIFORMS PER ML
OXYGEN PPM
D. O.
B. O. D.
30.4 28.8 34.5 44.3
28.0 24.3 32.0 37.0
35.7
33.0
46,000
240,000
35.4
37.8
Hazleton
Petersburg
Washington
Newberry
Eel River
Freedom
Spencer
Martinsville
Waverly
Indianapolis
Nora
Noblesville
Strawtown
Perkinsville
Anderson
Muncie
Winchester
R I V E R M I L E S

Euglena, but Vorticella and other forms contributed a considerable volume. Anderson (mile 297) undoubtedly contributed a portion of the pollution responsible for this burst of plankton, but it seems possible that the height of the peak is related to the heavy organic load introduced at Muncie. The plankton volume fell below Noblesville and by the time Nora was reached, a few miles above the city of Indianapolis, the total volume, and especially that of the Class II organisms, had decreased greatly. In passing through the city of Indianapolis, the plankton concentration of the White River was severely reduced. This may partly be due to the number of tributaries which enter the White River in this region, to the large portion of the water which passes through the city waterworks during low water, and possibly to specific pollution factors.

The plankton recovers slowly below Indianapolis. This continues until Martinsville is reached. Below Martinsville (mile 194), conditions seem to be favorable for the proliferation in great numbers of large species of diatoms, especially Stephanodiscus and Synedra. This diatom population continues on past the mouth of the Eel River to Newberry, where, possibly due to the diluting effect of this tributary, the total volume falls off. At Washington (mile 62), most of the Stephanodiscus have vanished and Class II organisms appear under the influence of fresh pollution at this location. From this point downstream the total volume of plankton falls off to approximately 1.5 M.p.p.m. above the mouth.

At Perkinsville, several miles below Anderson, bass, buffalo, shiners and a black bullhead were caught. The water was obviously dirty at this point, with algae covering the stream bottom. At Strawtown, several miles below, the appearance of the stream was much better, pollution not being obvious. At Noblesville, many shiners, some sunfish and some darters comprised the catch. Stream conditions appeared good. Local fishermen reported that bass, buffalo, carp, catfish, crappies, bluegills and other fish are caught in season.

At Nora, smallmouth bass and some shiners were caught under difficult seining conditions. Some large unidentified fish escaped. It is assumed that under better seining conditions the catch would have been considerably greater.

Below Indianapolis, above the last waste outfall, some sunfish and a largemouth buffalo were caught. The bottom was gravel, with a strong current, but considerable blue-green algae were visible. Fishermen reported that only carp and catfish were caught here. Fish, presumably mooneyes, were seen

breaking water occasionally at the mouth of the outfall. A local resident told of many fish deaths a distance above the sampling point a week or two earlier. The period of the slaughter coincides with that of the hottest weather of the month. The above story is borne out by the extremely numerous skeletons and weathered corpses of large fish along the shore.

At Martinsville, large common and quillback suckers, hogmollies, sunfish and numerous minnows are found. One largemouth black bass was caught. The river bottom consisted of black oily mud with a strong odor, and algal growth was plentiful. All the fish caught showed a tendency to the dark phase, which in the minnows was expressed so strongly that the dorsal color was bluish-black.

At Spencer, the bottom was muddy but had a sandy underlayer. There was a green covering on the flat rocks in the stream. Common and quillback suckers, spotted suckers, sunfish, channel catfish, shiners and chubs were caught and largemouth bass were very plentiful. It is possible that the fish were more active due to the rain which fell the previous night and the early part of the day.

At Newberry, largemouth bass were caught, as were some sunfish, shiners and darters. Channel catfish were numerous. There was no mud on the bottom, possibly due to the marked current, but algae were visible.

The Eel River, whose mouth lies above this point (plankton 0.6 M.p.p.m., D.O. 8.5 p.p.m.), had a number of largemouth bass, possibly some Kentucky bass and shiners, darters and some minnows. Below the sewer at Washington, the bottom was sandy but there was a slight odor to the water. Seining conditions were not good. Gar pike, largemouth black bass, quillback suckers and shiners were caught, while channel catfish and darters were also plentiful. Above Petersburg, the White River is joined by its East Fork, which appears to be a good stream (plankton 0.5 M.p.p.m., D.O. 7.75 p.p.m.). Conditions here were not very favorable for seining, but largemouth bass, channel catfish, quillback suckers, shiners and sunfish were caught. Blue herring were found in large numbers at this point. Below Petersburg, considerable mud was encountered in the White River. Channel catfish were plentiful, with mudcat also present. Small bass were numerous, many quillback suckers were found, and sheepshead, shiners, sunfish and several types of minnows were caught.

Below Hazleton, stream conditions looked good. Several largemouth bass and some gar pike were caught, sheepshead, mooneyes, quillback suckers and shiners were plentiful. No catfish were obtained, even after extensive seining. The bottom was sandy.

Above the mouth of the White River, largemouth black bass, small mudcat, sunfish and minnows were caught under unfavorable conditions. Buffalo, carp and gars were reported to be plentiful, bass less numerous, and it was said that an occasional sturgeon was caught. This information was derived from the proprietor of a local fishing camp. Some large, slimy fish (gar or sturgeon) tore a hole through the net and escaped.

Patoka River (mile 95) - The Patoka River was visited during the middle of September. The first samples were taken a short distance above the mouth. When first observed from the bridge, the water presented a greenish-blue appearance, due to some milky suspended material. Otherwise the water was very clear.

Several large carp and redhorse suckers were seen traveling downstream, while black catfish, a ten-inch bass, an eel and other large fish were seen moving slowly in various directions. No minnows were observed. The fish were making efforts to escape from the pool in which they were found, but were apparently unable to cross the shallows at either end. The fish were relatively sluggish and it was possible to capture a 23-inch dogfish (Amia calva) in a dip net. Although the condition of the water was attributed locally to the waterworks at Princeton, the waterworks records showed that the stream often was very acid due to mine drainage and pumpage. In addition, there was often a heavy salt load from oil well pollution, as well as high "hardness" values. A wave of acid water had passed downstream at about the time observations were made. One week later, the pH at the waterworks dam was 6.8. No fish could be found by seining. Plankton was 0.33 M.p.p.m. above the dam and 2.5 M.p.p.m. below. The waterworks operator reported that sludge was flushed into the stream at intervals of six months or longer. No records were obtained of the effects of this sludge upon the aquatic life of the stream.

Saline River

In early October the Saline River, a minor Ohio River tributary in Illinois, was extremely low and discontinuous, with almost no current. Some regions resembled stagnant sewers. Near the mouth the stream is situated in the Shawnee

National Forest. At flood season, this locality is a deep backwater of the Ohio River. The bottom consists largely of rock ridges, with deep pools between riffles.

Seining conditions were poor, but largemouth bass, logperch, crappies and small sunfish were caught. Minnows were seen in the shallows, and larger fish were breaking water in the middle of the stream. A ranger reported a considerable variety of fish, such as catfish, sheepshead, gar pike, etc. Plankton was plentiful, approaching 1.5 M.p.p.m. (Table 15).

Tradewater River

The Tradewater River is a narrow, deep Kentucky stream. At the time of observations in October, practically no water was flowing. Fish caught near Sturgis, Ky., consisted of common suckers, Kentucky bass, bluegills, sunfish, quillback suckers, sheepshead and some shiners. The water appeared green and dirty but the total plankton volume was only 0.17 M.p.p.m., almost half of this consisting of Class II organisms (Table 15).

Another sample taken near Providence, Ky., showed crappies, quillback suckers, mooneyes and some small sunfish and shiners. The water here was shallow and dirty and was used as a watering place for live stock. It is probable that this portion of the river was not connected with the lower river at this season.

Green River

The Green River rises in Casey County, Ky., and flows in a general westerly direction to join the Ohio River above Evansville, Ind. The length is 370 miles and the average slope below Mammoth Cave (mile 198) is about 0.5 feet per mile. It drains an area of 9,220 square miles.

The population of the Green River Basin in 1940 was 440,000, of which only about 10 per cent were found in incorporated towns, the largest of which was Bowling Green (pop. 14,585). The principal resources are coal, timber, asphalt, oil and gas. The principal industry is agriculture. Six locks and dams produce slack water up to Mammoth Cave, and one lock and dam each on the Barren and Rough Rivers produce slack water as far as Bowling Green and Hartford, respectively.

The Green River, for a large part of its course, is a wide deep stream and it was, therefore, difficult to estimate the fish population. The trap net was used on a number of occasions

and at times it was possible to seine immediately below the dams. Even at these locations, however, conditions were usually unfavorable for fishing. Bait fishermen, however, were successful at a number of locations. Fishing conditions were better in the numerous tributaries of the Green River, and results from these must be used to a large extent.

Plankton, on the whole, is extremely low all along the Green River. For the most part, the total volume is less than 0.2 M.p.p.m. (Table 15), although a sample taken at Dam 4 showed over 1 M.p.p.m. It should be pointed out that this dam lies below the mouth of the Barren River on which is situated the city of Bowling Green. Seining was possible at points from Dam 6 at Brownsville up to about Eunice, Ky. In this region could be found smallmouth and Kentucky bass, common, redhorse and hogmolly suckers, log-perch, darters, shiners and an occasional blue herring. Bass caught at Brownsville were a very translucent, pale color and may have been sick. At Munfordville, which is just within the limestone cave area, fishermen reported catches of large bass, pike and muskellunge. It is to be noted that the reserve alkalinity in this region of the stream (Munfordville to Brownsville and below) is approximately double that found higher up the stream. This is, of course, to be ascribed to the limestone drainage.

Trap net fishing between Brownsville and the mouth of the river was on the whole unsuccessful, due to the nature of the stream. Kentucky bass and sunfish constituted the catch. Mooneyes were often observed breaking water. Fishermen at Dams 3 and 4 had catches of bass and walleyed pike. At Livermore, at the mouth of the Rough River, natives report catfish as the exclusive catch. It was possible to seine the Green River at Rumsey. Bass, sunfish, channel catfish and shiners were collected. In addition to bass and minnows, blue herring were found at Spottsville, near the mouth of the river.

The tributaries of the Green River showed, on the whole, higher plankton and better fishing than the main stream. However, at this time (October), these streams were very low.

Pond River, into which the sewage of Madisonville is emptied, gave the only catches of small pike; sunfish, bullheads and shiners were also present. In addition to the Madisonville pollution, there were local pollutions at some of the sampling points, due to their use as water-holes and as pools for domestic fowl. At the mouth of the Pond River, largemouth black bass and Kentucky bass, possibly coming from the Green River, were captured. Natives report fishing in the Pond River to be

basically good, but frequent pollution by mine waters kills the fish. Plankton in the stream was uniformly high, approximating 1 M.p.p.m. Near the mouth, the Pond River receives the drainage of Cypress Creek which is highly polluted by mine wastes. At the time of sampling the pH was 3.2. Plankton was 0.26 M.p.p.m., almost half of which consisted of the diatom, Navicula.

The Rough River for the most part showed low plankton and a scarcity of fish. At Falls of Rough, where the plankton was 0.3 M.p.p.m. and considerably higher than that found at other points in the stream, sunfish were fairly plentiful, as were shiners and chubs. At Hartford, approximately 20 miles from the mouth of the river, fish were very scarce. Two pavement-toothed redhorse suckers and two shiners constituted the total catch. Acid mine drainage is a source of pollution. The higher points on the stream yielded hogmollies, darters, chubs and shiners.

The Nolin River is, for most of its course, a small stream, along which are situated several towns. At several points plankton is higher than in the Green River. Catches did not contain large numbers of fish, but among them were smallmouth bass, darters, sculpin, sunfish and shiners. The Nolin River runs through the limestone area and enters the Green River near Mammoth Cave.

The Barren River has a navigation dam below Bowling Green, but above that city it is a fairly small stream. The upper reaches consist of alternating shallow, narrow riffles, and large, deep pools. Fishing conditions were not good. Plankton above Bowling Green was less than 0.1 M.p.p.m., although it was somewhat higher in the region of the dam. Shiners, darters, hogmolly and common suckers and sunfish constituted the fish catch in the upper portions of the stream. Natives report a few bass present, especially in the spring. Below Bowling Green and Dam 1, log-perch, darters, bluegills, sunfish, common and redhorse suckers and many small mooneyes were caught. Shiners were seen in the water. Pike and bass fishing were normally good, but at the time of our visit, dynamiting and construction work which was going on nearby probably disturbed the fish.

The Mud River was sampled near its mouth, and yielded common and quillback suckers, crappies, sunfish, shiners, darters and some unknown striped minnows. At this point the stream was narrow and deep with a mud and humus bottom. At Lewisburg, the oxygen was 2.6 p.p.m. The water was black and many dead leaves were present. One shiner and one darter were the sole

catch. It is possible that the dead leaves may have been responsible for the color of the water and the low D.O. values. Reserve alkalinity in this vicinity was much higher than at the mouth.

Cumberland River

The Cumberland River is formed by the junction of Poor and Clover Forks in the southeastern part of Kentucky. It flows southwest into Tennessee, then northwest into Kentucky and finally empties into the Ohio River at Smithland, Ky. Its length is about 687 miles. The average slope below Burnside, Ky., (mile 516) is about 0.6 feet per mile. The Cumberland drains an area of roughly 18,000 square miles. The river has been canalized for 331 miles by the construction of fourteen locks and dams.

The population of the basin in 1940 was 1,129,000, of which 277,724 were in communities of over 2,500. Over half of these, or 167,402, lived in the city of Nashville.

The principal resources of this area are coal, zinc, iron, limestone and oil. The principal industries are agriculture, products of cement, rayon textiles and chemicals.

Observations were made on the Cumberland River during the months of October and November, 1940. Samples were taken from Dam 8 (mile 317) in Tennessee, to Dam F in Kentucky, approximately 45 miles from the mouth of the river. Heavy rains occurred during the survey period, but some observations, both before and after the rain, indicated that no important variation was introduced by this factor. Likewise, an unseasonable cold spell occurred towards the end of the period of observation, which brought the water temperature in some cases down to 10° C. Both of these conditions, the rain and the drop in temperature, may affect the absolute values of the samples from Dams 4 to 8 and from Dams C to F. The center region of the river was studied prior to the onset of the rains and, therefore, may be considered fairly representative of the late summer conditions. The probable effect on the plankton volumes at the two ends of the observation range is not more than 100 per cent, which does not affect the general plankton picture of the stream (Figure 13 and Table 16).

From Dam 8 to Dam 3 the plankton level was quite low. The slight rise in the values at Dam 4 may perhaps be attributed to the discharges from Gallatin and Lebanon, which are situated

Fig. 13

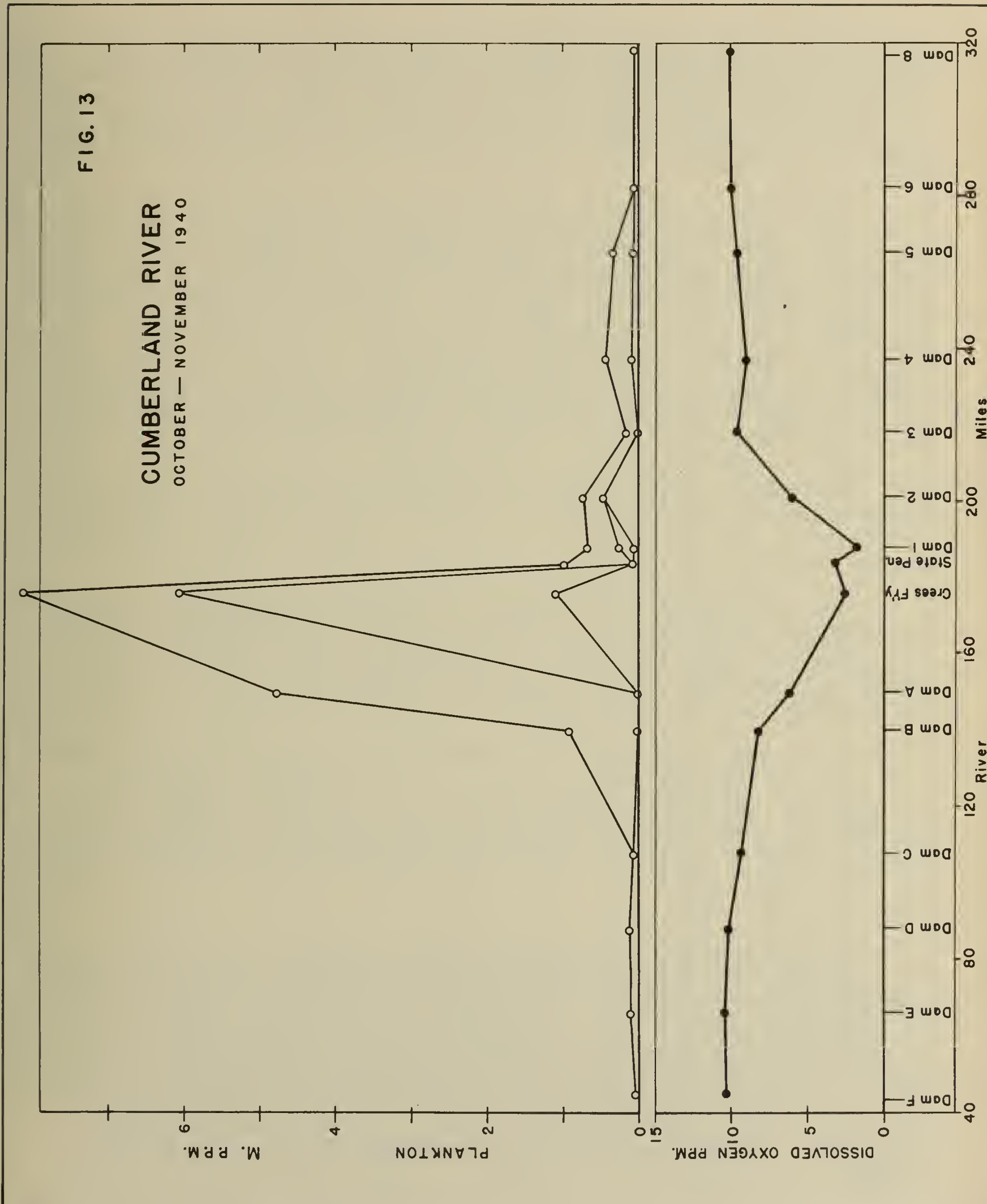


FIG. 13
CUMBERLAND RIVER
OCTOBER — NOVEMBER 1940
PLANKTON M. P.P.M.
0
2
4
6
DISSOLVED OXYGEN PPM.
15
10
5
0
Dam F
Dam E
Dam D
Dam C
Dam B
Dam A
Crees F'y
State Pen.
Dam 1
Dam 2
Dam 3
Dam 4
Dam 5
Dam 6
Dam 8
40
80
120
160
200
240
280
320
River Miles

on small side creeks. From Dam 3 to Dam A is found a relatively concentrated human population. Between Dams 2 and 3 is located a rayon plant, with a grouping of small towns in the vicinity. The city of Nashville, with its large concentrated population, suburbs and large number of industries, is located just above Dam 1.

It is seen that the location of the population is indicated in both the plankton and dissolved oxygen curves. The plankton commences to rise above Dam 2 and reaches a peak some miles below Nashville. This peak, due largely to Class II organisms, falls off slowly down the river. The last of this plankton hump is found somewhere below Dam B. The State Penitentiary, several miles below Nashville, contributes a fair amount of waste. Between this location and the next sampling point, Crees Ferry, is located a paper mill, which causes a very noticeable blackening of the stream below its location.

The oxygen curve shows a distinct drop between Dams 2 and 3 and reaches a minimum at Dam 1 immediately below Nashville. Recovery is slow, and is not complete before Dam B, approximately 48 miles downstream.

The Cumberland River shows in almost diagrammatic form the effect of an isolated source of heavy pollution upon a relatively clean stream. It is possible that if there were no navigation dams, the effect of Nashville pollution would be evident further downstream.

The State Department of Conservation plants fish rather extensively throughout portions of the Cumberland Basin in Tennessee. This may account for some of the specimens found in side streams and, to a certain extent, in the Cumberland River itself. It is evident from the catches, however, that there is sufficient nutritive material to enable the fish to grow to good size.

In fishing the Cumberland River, it was the practice to set the trap net in the current below various dams. Shallower tributaries were seined. At Dam 8 an overnight catch consisted of two crappies; at Dam 6, crappies to ten inches in length, Kentucky smallmouth bass to nine inches, bluegills and sunfish. Other fishermen caught sheepshead, and redhorse suckers. At Dam 5 fish were more varied, consisting of crappies, darters, log-perch, shad, and numerous shiners, chubs and quillback suckers. Bass were undoubtedly present, although none were caught.

Kentucky bass were found at Dams 3 and 4, with shad seen in fair numbers. These last fish were eating the algae from the dam and the lock walls. Dam 2 also yielded Kentucky bass and sunfish. Dam 1 was visited twice, once immediately before and once immediately after a rain. Water conditions were very bad at the time of the first visit, the D.O. being less than 2 p.p.m. above the dam. Crayfish were found along the bank, approximately half of them being completely out of water, apparently to avoid the asphyxiating conditions in the stream. These crayfish were often very heavily covered with a white growth, presumably fungus. In the lock itself, water, which had been isolated from the river overnight, contained less than 0.7 p.p.m. of oxygen. Fish were numerous in this water and swam either at the top or close to the top, seeming to prefer the region of the lock walls where algae were growing. They came to the top apparently to gulp air. Some of these fish could be captured by means of a dip net. Among them could be seen catfish and gars of large size, shad, sunfish, minnows and bass. About four days later, following a rain, the oxygen was approximately 6 p.p.m. and crayfish were no longer visible along the banks.

Sheepshead, numerous Kentucky bass and crappies were found at Dam A, and Dam B yielded Kentucky bass. The fish caught at this Dam showed very noticeable tail and palate infections. After this find, such infections were watched for in all cases and found to be fairly common, although not quite so numerous, both above and below this point. The State Conservation Department informed us that this was an infection by fungus with which was associated a species of Hydra.

At Dam C the water was somewhat muddy, due to the discharge of the Red River, upstream from that point. The net catch consisted of smallmouth buffalo, channel and mud catfish and a number of sheepshead.

At Dam D the catch was Kentucky bass, while at Dam E a white bass and a large number of channel catfish were caught. Dam F yielded Kentucky bass and crappies in the fyke net, while shiners and shad were caught in the lock with a dip net. A large white bass was also seen swimming in the lock water. It may be noted that at this dam, which is the site of the Western State Penitentiary (Eddyville), with a population approaching 2,000, the bass were the fattest found on the river.

Stone's River, which enters the Cumberland above Nashville, showed a heavy algal growth. Oxygen was good and a variety of fish were found. The species captured were sunfish, bluegills,

Kentucky bass, mud catfish, shiners, darters, smallmouth black bass, log-perch and chubs. Frogs, tadpoles and salamanders were caught and the crayfish found at this point were very clean and brightly colored. The plankton found was of approximately the same level as the catch at Dam 1. Seining conditions at the Harpeth River were not good. Two kinds of minnows were caught. It is reported that a chemical plant empties its wastes into this river. The electrical conductivity of the water was not noticeably higher than that found in Stone's River, although samples were taken following a rain. The total plankton was less than 0.1 M.p.p.m.

Main Ohio River

The Ohio River is acid from Pittsburgh to mile 172 (below Pittsburgh) at Marietta, although on occasion the effects are felt as far downstream as the mouth of the Kanawha River at mile 266. The River is near neutral (pH 6.9 - 7.4) from Marietta to mile 320. From mile 320 the alkalinity increases slightly to the mouth (pH 7.4 - 8.5). The Ohio seems to be relatively stable chemically and bacteriologically, compared to its tributaries. Cincinnati and, to a lesser extent, Louisville, make their locations known by their effect on the D.O., B.O.D. and coliform count. With these exceptions, however, and that of a possible gradual increase in B.O.D. and bacterial count in passing down-river, there is relatively little chemical or bacteriological variation. This can be ascribed to the large dilution factor due to the stream size.

A large number of plankton samples was collected from the middle third of the river, from mile 316 (above the mouth of the Big Sandy) to mile 531 (Dam 29), in the interval from May 1 to December 28, 1939, (Table 17). Fewer samples were taken in the upper and lower thirds in 1940. No fish collections were made.

The plankton of the Ohio River contains fewer genera and species than that of the main tributaries. The plankton volume immediately below Pittsburgh, at the Emsworth Dam, in October, 1940, was extremely low, less than 0.1 M.p.p.m., and consisted mainly of *Closteriopsis* and some small green algae. The population fluctuated, with an irregular tendency to increase downstream to Marietta, Ohio, (mile 172). The low plankton volume and the limited variety of planktonts are correlated with the acidity of the upper portion of the river. During the summer period, the river in the region above Marietta may reach

a pH value as low as 4.1, and is usually acid, even in the spring and early summer.

In June and July the plankton volume in the neutral portion of the upper third of the Ohio (below Marietta) was occasionally as high as 4 M.p.p.m., while in August and September the volume remained at lower levels. The most numerous forms in the June-July period were Chrysococcus, Chlamydomonas and a variety of green algae (diatoms). Closteriopsis, Chlamydomonas and Cyclotella dominated the fall plankton in this region.

In the middle third of the Ohio River, in May, 1939, a large bloom of diatoms was the striking feature of the plankton. The principal genera involved were Asterionella, Gomphonema, Nitschia and Synedra. The highest volume value of plankton found was 74.7 M.p.p.m. at Dam 37 (Cincinnati) on May 12. There were no data from above mile 405 or below mile 531 to indicate definitely whether this bloom was local, general, or was moving downstream. The data at hand suggest that there was a movement of the diatom bloom downstream. The data indicate that in general the plankton population at Dams 37, 38 and 39 (below Cincinnati) was greater than at the stations above. This may be attributed to the fertilizing effect of the waste from the Cincinnati area.

The high plankton volumes in the lower part of the river, from mile 600 to mile 730 (1940), are due largely to diatoms, principally Melosira, Synedra and Fragilaria. Asterionella becomes important in the samples near the mouth of the river below mile 800 (November).

The Ohio River seems to possess a plankton population which is characteristically different from that of its tributaries. The outstanding characteristic of the Ohio plankton is the presence of large numbers of diatoms of genera not prominent in the plankton of its tributaries. Modifying this is the acid condition in the upper portion of the river. This results in Closteriopsis, the form dominating the acid waters of the Monongahela River, extending its range down through the acid regions of the Ohio River below Pittsburgh.

The equipment on hand was not adequate to make a detailed study of the fishes of the Ohio River. Considerable fishing, however, is done with set lines by the river people, and large catches of carp and channel catfish were reported at various places along the river below Liverpool, West Virginia. Many gar pike and mooneyes were seen breaking water at Marietta, Ohio, and Ashland, Kentucky. Fishing for river chubs is a favorite sport for children along the middle third of the river, and an occasional walleyed pike is taken.

DISCUSSION

Owing to the large area of the Ohio Basin (204,000 square miles) and the short time allotted to the survey (two years), it was impossible to attempt a completely satisfactory biological study. It is realized that there are inaccuracies in the method of sampling and computation and the danger of misinterpretation due to the small number of samples taken at a given point. It is well known that the biological picture of a stream varies with the year, the season and even the time of day. While the data cannot be considered complete, the general agreement between series of samples and the support of comparative data strengthen the deductions from a given sample. The long series of samples taken at fixed points in the Ohio Basin from May through December, 1939, show the influence of seasonal and climatic factors on the plankton and, through evaluation of these influences, it has been possible to increase the significance of the interpretations of individual samples.

A study of the data presented brings out the following topics for discussion.

Organic Pollution

Pollutants which enter streams from city sewers or organic industrial plants, such as canneries, meat-packing houses and creameries, affect the aquatic life in a variety of ways. The waste may have an immediate toxic effect or, as is more often the case, the waste may induce rapid multiplication of aerobic bacteria which sharply lower the dissolved oxygen concentration, frequently to the asphyxial level for fishes, and often to depletion. This is probably the most common cause of mass death of fish in streams of the Ohio Basin (see Trautman[5]).

The lowering of the dissolved oxygen concentration, accompanied by high biochemical oxygen demand and a high count of coliform bacteria (if the pollutant is sewage) is evident for a distance, below the source of pollution, which depends upon the temperature, rate of flow, and type of stream. It may vary from a few hundred feet to several miles. Biologically, this region is dominated by Class II planktonts, and the fish are principally of the coarse varieties, such as carp and buffalo. Abundant fungi and stalked ciliates may be attached to solid surfaces.

This zone gradually blends into the next, which is characterized by a large variety and volume of photosynthetic plankton

organisms and a high diurnal variation in the dissolved oxygen concentration, from supersaturation on some afternoone to very low values before dawn (see Denham[6], and Butcher, Pentelow and Woodley[7]). This marks the maximum fertilization effect of the pollution introduced upstream. In this region is usually found a large mixed fish population.

Further downstream, the high concentration of nutritive materials has been greatly reduced by the heavy upstream growth of plankton, and only the thrifty forms persist (Chrysophyceae, Cryptophyceae, and certain diatoms). This reduction in fish food has a direct effect upon the fish population, so that the game fishes are the dominant forms and the numbers of plankton feeders are reduced.

Where proper treatment is given to the wastes before they are turned into the stream, the early obnoxious stages of the natural purification processes are greatly reduced or entirely eliminated. Primary treatment plants, which remove the solid suspended materials from the wastes, result in less sludge being deposited in the stream, and in more immediate and rapid decomposition of the soluble materials. If the effluents are introduced into a stream where proper dilution occurs, conditions may never become obnoxious. If the treatment plant effluent forms a larger portion of the total stream flow, as in the Vermilion River below the Danville treatment plant, conditions may become acute for aquatic life, but the acute conditions are relieved in a comparatively short stretch of the stream, and the fertilization effect predominates.

The aim of secondary treatment of wastes is not only to remove and break down the solid components of the waste, but, by means of trickling filters or activated sludge, to allow a portion of the bacterial action to take place before the waste enters the stream, thus lowering the biochemical oxygen demand of the effluent and presenting it to the stream in a form more available for the plankton. This results in an even more marked reduction of the region of acute conditions and of the time and distance before the peak of the plankton volume is reached. Ideally, there should be no harmful effects from the effluent of a secondary treatment plant on fish life.

In practice, the results achieved by this type of treatment are dependent upon the efficacy of the plant and the total amount of waste treated. Thus, Peru (pop. 12,000), on the Wabash River, with a secondary treatment plant operating for only a few months before the time samples were taken, showed no obnoxious oxygen conditions and an immediate heavy growth of algae and plankton below the plant effluent. The stream

cleared itself of even this index of pollution in a very short distance. On the other hand, Muncie (pop. 46,000), on the White River, despite extensive corrective measures, contributes a load of residual organic material that is important in relation to the size of the stream at that point, and biological conditions are affected for some distance. On the same river, but at a point where flow volume is somewhat greater, the much larger city of Indianapolis (pop. 370,000) also affects the river B.O.D., D.O. and biology, but the effect is not in proportion to that at Muncie.

It should be pointed out that the introduction of untreated industrial wastes which are not necessarily available in any form for plankton food, complicates somewhat the natural purification processes. Thus, the entrance of creosoting wastes together with untreated sewage, as in one instance, may greatly slow down the bacterial decomposition of the organic matter, and result in a greater downstream propagation of the obnoxious stages of pollution. In addition, the presence of complicating toxins may appreciably raise the minimum oxygen requirement for fishes (due to increased metabolic rate) and thus cause an oxygen level, which may be ordinarily tolerated, to become definitely lethal.

As has been noted by other workers,[8] the presence of high pollution renders the incidence of parasitizations and developmental abnormalities much higher in the fish population. Thus, in the Vermilion River, below Danville, where the fish population was definitely high, parasitized fish and deformed fish were numerous. A more striking example was found in the Big Blue River, a tributary of the White River, where the fish taken below Carthage were all extremely heavily parasitized by organisms causing black or brown spots in the skin. The parasites were found in abundance up and down the stream, which is subject to repeated pollution, but the heaviest incidence of the parasites occurred at the location mentioned.

Industrial Wastes

The industrial establishments in the Ohio River Basin, in addition to canneries, creameries and meat-packing plants, are steel mills, coal mines, paper and pulp mills, distilleries and breweries, and oil and gas refineries. The acid wastes from steel mills and coal mines will be discussed separately.

The majority of these plants are situated in the large cities in the heavily populated area, such as along the Miami,

Wabash and Ohio Rivers. Thus, it is difficult to separate the effects of the industrial waste from those of the domestic sewage that is entering the stream at the same location. Often, industrial wastes enter the city sewers. The most satisfactory way to determine the effects of industrial effluents is to study small streams on which are located isolated plants. Increase in temperature due to hot effluents must be considered in addition to the chemical nature of the wastes.

Oil and gas refineries are found along the length of the Elk River, from Sutton to the junction with the Kanawha at Charleston. An isolated refinery is found at Huntington, W.Va., at the mouth of the Big Sandy. While the most prominent effect of the pollution is severe tastes and odors in local water supplies, there is an important effect on the fish (see also Shelford[9]). The Huntington plant causes the flesh of the fish at the mouth of the Big Sandy to taste of petroleum. The pollution along the Elk River has contributed to the absence of fish in that stream (September). The plankton of the Big Sandy is too low to draw any conclusions as to the effect of oil from the Huntington refinery on these organisms. The Elk River plankton is also low, but as the entire river is affected, it is not possible to obtain unaffected samples for comparison.

The effect of coal washeries is shown along the Tug Fork of the Big Sandy. These detract greatly from the suitability of this stream and many small tributaries for fish life. The water is black and a bottom layer of coal particles is deposited for miles below a washery. A few plankton forms, such as Navicula, Chrysococcus, Cryptomonas and Chlamydomonas, are present. These streams are alkaline.

A paper mill and tanneries on the Clarion River, a tributary of the Allegheny in Pennsylvania, discolor the water for many miles downstream. The Allegheny itself was colored for a considerable distance below the entrance of the polluted tributary. The plankton population of the Clarion at Cooksburg in July, 1939, consisted of fair numbers of Mallomonas, Chrysococcus, Chlamydomonas and Peridinium. There was a large mixed fish population. The flesh of the fish was tainted, making it inedible. A paper plant below Nashville, Tenn., apparently does not affect the plankton of the Cumberland River, although the stream is blackened.

Another type of pollution, consisting of cellulose and lignin fibers, resulting from paper and strawboard manufacture (the Wabash watershed and others), may clog the gills of fish, causing death; may increase the turbidity to the point of affecting the plankton; may form a sludge layer on the bottom of

the stream, and may eventually be attacked by specialized bacteria, and so contribute to the oxygen demand. Many types of plants discharge wastes having a large oxygen demand, resulting in the depletion of oxygen and the killing of many fish annually.

Pollution from plants manufacturing chemicals may be serious in some localities. A plant on the Kanawha River, above Charleston, W. Va., has been the subject of a report by Ellis.(10) Another source of industrial pollution upon which data collected during the present survey is insufficient is brine pumpage from oil wells. This is serious, as fresh water organisms in general are not adapted physiologically to withstand heavy salt concentrations (see Ellis[11]). Tannery wastes may also be important in some localities.

Acid Pollution

The entrance of sulfuric acid from active and abandoned coal mines is one of the most important problems of stream pollution throughout the Ohio River Basin. Many abandoned coal mines that have not been sealed are daily pouring tons of sulfuric acid (formed by oxidation of iron sulfides) into these streams (Hodge[12]). Many of the active mines are working only part of the year and, unless pumping is carefully controlled when operations are resumed, a very heavy load of acid may be discharged into the watercourse. The acidity of acid mine drainage streams has been known to reach pH 2. This high acidity eliminates all fish, and only a few plankton forms exist.(11) Euglena mutabilis may grow in sufficient numbers to form a bright green carpet over the entire bed of small acid streams of pH 4 or less.

Acid streams are characterized by a deposit of yellow to brownish precipitate (iron oxide) that covers the bottom. This deposit may remain long after sealing has prevented air from entering the polluting mines and the source of acid thus eliminated. The bottom of the stream, therefore, remains unsuitable for egg deposition and development of fish and their food organisms, long after the water acidity has been corrected.

The acid drainage, chiefly from mines but also to a lesser extent from the steel mills near Pittsburgh, Wheeling and Steubenville, lowers the pH of the Ohio River to 6 or less as far downstream as Marietta, Ohio, and is an important factor in the low plankton population in the upper portion of the Ohio River, and the cause of downstream fish migration.

Stream Zones

A summary of the observations over the Ohio River watershed shows that streams and regions of streams may be divided into the following five types of zones, according to the dissolved oxygen, pH, plankton and fish data:

(1) Zone of heavy organic pollution: dissolved oxygen not higher than 3 p.p.m. even during the daytime; plankton volume variable, principally composed of Class II organisms; pH tending toward acidity. Fish mostly absent, occasionally buffalo, carp and sunfish.

(2) Zone of intermediate pollution: dissolved oxygen between 3 and 5 p.p.m. in the daytime; plankton volume is higher than in (1), with an increasing number of chlorophyll-bearing forms, although still composed largely of Class II organisms; Oscillatoria and other blue-green algae common, and a growth of green algae commencing to appear along the stream margin; pH slightly higher. Fish, in addition to carp and buffalo, are more abundant but show a tendency to sickness, deformity and parasitization.

(3) Fertile zone: dissolved oxygen not below 5 p.p.m. and subject to diurnal fluctuations; plankton over 1 M.p.p.m. (usually several M.p.p.m.), and largely green forms, of the Intermediate group, marginal growth of algae very noticeable in some places; pH alkaline and tending to rise, especially during sunny periods. Fish are variable, plentiful and healthy; large numbers of suckers, sheepshead, catfish and other market fish are present.

(4) Game fish zone: dissolved oxygen above 5 p.p.m., and usually approximating saturation values; plankton usually between 0.3 and 1.0 M.p.p.m., with Class II forms scarce; pH neutral to alkaline. Game fish (basses and perches, pike, etc.) and forage fish predominate.

(5) Poor fish zone, due to (a) natural conditions, or (b) acid pollution: (a) Naturally poor fish zone: dissolved oxygen above 5 p.p.m. and usually approximating saturation values; plankton less than 0.3 M.p.p.m. and consisting almost entirely of Class I organisms. Fish are mainly the game fish types. Streams that may be classified by the fisherman as "good" trout streams are, by the above biological standards, "poor" streams, i.e., infertile and relatively low in biological population. (b) Acid polluted zone: the pH is variable, and the water is sometimes acid. If the stream is highly acid, there may be no fish at all.

The (5-a) type of stream is characteristic of the tributaries coming to the Ohio from the south, where the winter period is not marked, so that there is generally a lower level of, and less seasonal fluctuation in, the aquatic life. It is also true that these streams usually have relatively rocky, infertile watersheds, and are often of the (5-b) type or subject to acid pollution.

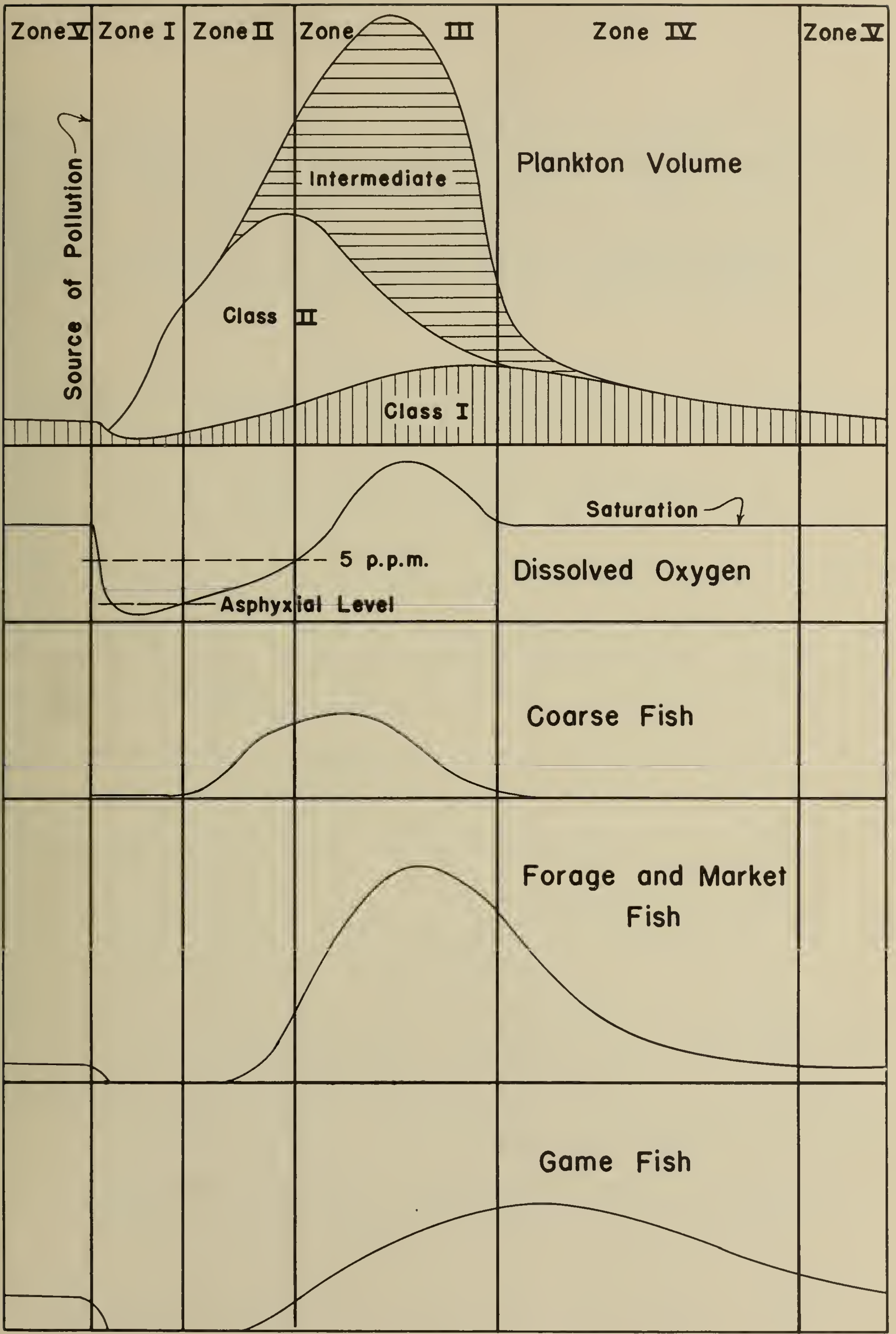
These relationships of the different zones are illustrated graphically in Figure 14. The plankton curve shows the dependence of Class II organisms upon a rich food supply and that of the Intermediate forms upon a less concentrated medium. Pollution affects the Class I organisms to a certain extent, but they are less affected by either favorable or unfavorable conditions than are the members of either of the other two groups of planktonts. For this reason they are the characteristic forms of "clean waters," as well as persisting through polluted areas.

In the region where the oxygen levels lie between asphyxial values and 5 p.p.m., fish normally found in oxygen-poor situations predominate (carp, buffalo). Fish of other types are abnormal under these conditions. Occasional abnormal fish may be found in situations where the dissolved oxygen is over 5 p.p.m., when the upstream pollution is very intense. The field results show that the 5 parts per million level seems to form a natural dividing line between good and bad fish conditions, corroborating the findings of Ellis.[11] Under certain conditions, the level may be set higher, but there is no evidence that it should be set appreciably lower.

The zones illustrated in Figure 14 are shown as possible phases in a continuous situation, although it is understood that in a given stream certain zones may never appear. The Cumberland River, for example, is an almost diagrammatic illustration of the condition depicted, with Nashville serving as the site of pollution. The Miami River, on the other hand, from Dayton downstream, falls entirely in zones (1), (2) and (3). The Wabash River watershed lies in generally fertile, glaciated territory, and its unpolluted regions correspond to zone (4) conditions. Mountain streams, acid streams and, in general, the infertile southern streams in their unpolluted reaches, correspond to zone (5). Light pollution may improve them biologically at local points.

The zone into which a given point of a stream may fall will vary with conditions. During spring high water, for example, zone (1) and (2) conditions are scarce. As the year advances and low-flow conditions set in, the polluted areas

Fig. 14


Zone V
Zone I
Zone II
Zone III
Zone IV
Zone V
Source of Pollution
Plankton Volume
Intermediate
Class II
Class I
Saturation
5 p.p.m.
Asphyxial Level
Dissolved Oxygen
Coarse Fish
Forage and Market Fish
Game Fish

are more distinct. It should be stressed that it is the summer low-water period that is critical to the fish population of a stream, and not the favorable high-water conditions. A period which exterminates a fish population may be only one day of the year, but it is not compensated by the tolerable conditions of the other 364 days. Likewise, a single epidemic of a water-borne disease renders insignificant the years between it and the previous outbreak.

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EXPLANATION OF TABLES

Mile	Refers to the distance from the junction of the stream with the Ohio, except the White River (Table 14) where it refers to the distance from its junction with the Wabash. The mileage of the Ohio River is taken from Pittsburgh, Pa.
Samp.	Samples taken.
Volume:	Plankton in thousands of parts per million.
T	Total plankton M.p.p.m.
I	Class I organisms M.p.p.m.
II	Class II organisms M.p.p.m.
Ave.	Average volume, determined by dividing the total volume of plankton by the number of samples; or the total number of organisms of the various groups, divided by the number of samples; or the total B.coli, B.O.D., D.O., Tby., pH, Temp., divided by the number of samples.
Max.	Highest value obtained during period under question.
Min.	Lowest value obtained during period under question.
Chr.	Chrysophyceae, numbers per ml.
Cry.	Cryptophyceae, numbers per ml.
Chl.	Chlorophyceae, numbers per ml.
Myx.	Myxophyceae, numbers per ml.
Bac.	Bacillarieae, numbers per ml.
Eug.	Euglenophyceae, numbers per ml.
Pro.	Protozoa, numbers per ml.
B.Coli	Coliform bacteria, most probable numbers.
B.O.D.	Biochemical oxygen demand, 5 days at 20 °C., in parts per million.
D.O.	Dissolved oxygen, parts per million.
Tby.	Turbidity, parts per million.
Temp.	Temperature, degrees Centigrade.

TABLE I

BIG MIAMI RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	BOD.	D O.	Tby.	pH	Temp.
Cleves	4.2	5-16		Ave.	3.0	.93	.63	103	47	409	11	996	23	18	217	3.61	8.70	60	7.9	17.0
		to	22	Max.	9.8	4.6	3.6	584	504	1045	46	7857	84	52	930	5.34	10.00	310	8.3	26.0
		12-12		Min.	.21	.07	.05	20	0	28	0	56	0	0	21	1.25	6.67	8	7.6	5.0
Venice	24.8	5-1		Ave.	8.2	3.5	1.3	84	169	972	7	3206	73	41	303	4.58	8.41	30	8.1	22.3
		to	6	Max.	16.9	7.7	2.7	352	340	2384	36	9044	276	84	930	5.84	9.82	40	8.3	26.5
		6-28		Min.	4.7	.38	.66	4	60	116	0	260	4	18	36	2.57	6.61	20	8.0	14.0
Hamilton Above	35.9	6-28		Ave.	5.6	1.6	1.4	48	144	651	22	2255	224	26	389	3.45	5.77	-	7.7	24.9
		to	4	Max.	15.8	5.0	4.8	124	476	1448	36	7440	708	62	930	4.20	6.43	-	7.7	26.5
		9-15		Min.	1.8	.04	0	6	4	152	4	36	28	0	46	2.31	4.78	-	7.6	23.5
Hamilton Below	30.4	7-21		Ave.	5.2	1.4	2.2	108	72	611	41	2047	119	85	2747	5.02	4.93	-	7.6	23.5
		to	6	Max.	8.4	4.2	4.7	216	138	898	84	6384	162	292	11000	11.72	6.95	-	7.8	27.5
		10-27		Min.	.76	.06	.34	15	4	60	8	36	62	12	430	1.46	1.90	-	7.5	19.0
Middletown Above	57.0.	6-27		Ave.	3.0	1.1	.4	99	106	558	31	1522	84	24	257	4.81	8.44	-	7.7	23.1
		to	4	Max.	8.4	2.1	2.7	224	293	1646	64	3254	153	40	750	7.43	12.07	-	7.9	25.0
		9-29		Min.	1.0	.25	.32	16	16	68	2	36	40	3	36	2.38	7.05	-	7.4	20.5
Middletown Below	50.8	6-28		Ave.	4.3	.96	1.8	75	65	492	18	1313	61	20	1326	5.70	5.26	-	7.7	23.9
		to	7	Max.	10.2	1.8	6.5	204	100	1184	56	3492	252	40	4600	9.60	6.19	-	7.9	26.5
		10-27		Min.	1.3	.15	.09	0	8	52	0	20	4	4	390	2.87	3.54	-	7.5	19.0
Franklin Above	62.8	7-11		Ave.	7.6	.95	4.8	57	74	488	43	880	271	65	573	3.38	7.43	-	8.0	23.8
		to	6	Max.	29.1	2.3	23.6	168	124	874	56	88	796	116	2400	4.17	7.57	-	8.2	26.5
		9-14		Min.	1.7	.46	1.1	0	20	72	12	32	64	4	36	2.28	7.13	-	7.9	22.0
Franklin Below	59.6	7-11		Ave.	8.3	1.0	4.2	168	135	726	54	991	225	93	4472	5.00	6.15	-	7.8	23.4
		to	7	Max.	22.2	1.3	18.6	680	195	1268	89	2364	563	276	11000	8.50	7.05	-	7.9	26.5
		10-26		Min.	2.9	.73	.07	9	60	78	0	74	40	16	91	2.72	4.10	-	7.6	22.0
Miamisburg Above	71.6	6-27		Ave.	8.0	2.1	2.2	88	133	464	79	1001	146	35	558	2.94	7.71	-	8.1	23.0
		to	9	Max.	15.0	10.7	12.4	322	456	876	244	2834	186	68	2400	4.06	9.50	-	8.2	26.5
		10-26		Min.	1.4	.19	1.5	4	12	76	8	56	32	4	91	1.86	6.83	-	8.0	17.0
Miamisburg Below	66.5	6-27		Ave.	4.9	.79	2.3	59	113	453	29	612	200	42	2214	4.22	5.88	-	7.9	23.0
		to	9	Max.	10.9	1.3	9.0	96	436	1476	102	2368	578	100	11000	6.73	6.97	-	8.0	26.0
		10-26		Min.	1.2	.20	.30	3	16	45	4	0	32	3	430	2.41	4.70	-	7.7	17.0
Phoneton	97	7-24	1		5.7	2.9	.28	12	34	684	74	958	59	4	-	-	-	-	8.0	25.0
Tippecanoe City, Above	108	7-24	1		4.8	.96	.64	260	0	1084	72	1644	12	292	29	5.36	5.96	48	7.9	22.5
Below	103	"	1		6.5	1.3	.33	216	8	1398	215	2208	32	48	460	4.46	4.64	37	7.8	24.0
Troy Above	114	9-14	1		4.8	.76	1.6	88	4	1097	268	1346	140	0	36	4.99	10.67	35	8.3	27.0
Below	112	"	1		2.4	.48	.77	52	4	632	140	716	64	0	43	3.59	3.09	25	8.0	27.0
Piqua Above	123	9-13	1		1.6	.96	.16	144	4	436	120	1420	44	12	93	2.08	10.80	35	8.3	21.0
Below	120	"	1		1.6	.24	.29	128	8	420	76	588	56	8	2400	7.64	7.61	25	8.1	13.5
Sidney Above	137	9-13	1		1.2	.67	.17	200	0	220	24	388	72	4	9.1	2.09	9.02	38	8.1	19
Below	132	"	1		14.0	12.1	1.0	140	0	132	100	3618	80	0	11000	8.44	7.27	25	8.1	20
Loganville "	155	7-25	1		1.4	.04	.83	0	2	72	72	38	24	2	-	-	-	-	7.6	26
Russel Point	164	7-25	1		1.2	.12	.28	9	9	152	540	138	39	3	-	-	-	-	7.8	-

TABLE 1, cont.

WHITEWATER RIVER

Station	Mile	Date 1939	No. of Samp.	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli.	BOD.	D O.	Tby.	pH	Temp.
Harrison	Above	7-13	1	2.9	.38	.33	40	188	772	0	152	80	24	15	0.94	7.77	-	-	24.0
	Below	"	1	5.1	.79	.54	24	568	1708	8	284	86	8	93	1.31	8.00	-	-	23.5
Brookville																			
East Fk.	Above	7-13	1	4.4	.94	1.2	12	164	548	0	484	156	0	24	0.99	9.08	-	-	23.5
West Fk.	Above	7-13	1	3.1	2.0	.16	20	80	312	4	218	30	12	9.3	.89	9.30	-	-	24.5
	Below	7-13	1	.62	.18	0	16	63	254	3	134	23	0	930	1.07	7.85	-	-	23.5
Connersville	Below	8-9	1	.98	.55	0	36	60	60	0	168	12	0	430	1.60	6.95	-	-	24.0
Cambridge City	Above	7-12	1	1.6	1.4	1.0	4	8	32	0	344	12	4	93	0.90	10.34	-	-	22.0
	Below	7-12	1	1.7	1.1	.29	10	60	140	5	375	50	0	93	0.90	11.51	-	-	22.5
Hagerstown	Above	7-12	1	.57	.51	0	0	0	15	0	165	0	0	23	2.05	11.40	-	-	23.0
	Below	7-12	1	.99	.85	.06	25	5	30	0	343	30	10	29	0.77	8.75	-	-	20.5
Richmond	Above	7-12	1	7.1	6.7	.24	0	30	45	0	530	25	10	93	1.34	7.78	-	-	23.5
	Below	7-12	1	16.2	12.1	3.6	5	70	95	5	1580	300	5	150	2.75	7.97	-	-	22.0
STILLWATER RIVER																			
Englewood	Above	7-24	1	3.1	.55	.76	15	101	444	15	42	147	0	-	-	-	-	7.8	-
W. Milton	Above	9-15	1	.92	.44	.18	336	0	248	0	752	24	12	23	3.03	8.15	37	8.0	22.5
	Below	"	1	1.1	.45	.02	498	0	187	28	492	11	8	93	3.02	6.88	51	7.9	22.5
Covington	Above	9-20	1	.87	.42	.24	172	8	32	0	4	8	12	24	2.12	6.45	70	8.0	15.0
	Below	"	1	.79	.20	.09	280	25	116	4	76	20	16	910	2.08	4.84	33	7.9	17.0
MAD RIVER																			
Springfield	Above	7-25	1	.24	.23	00	0	3	0	0	105	0	3	-	-	-	-	-	-
	"	7-24	1	.59	.58	00	0	40	30	0	255	0	0	-	-	-	-	7.8	20.0
Springfield	Below	9-12	1	6.2	6.2	00	0	4	4	8	628	4	4	460	2.44	8.38	10	7.8	18.0
Urbana	Above	9-14	1	2.6	2.6	00	0	0	8	0	260	0	0	15	1.40	8.94	10	7.9	20.0
	Below	"	1	1.9	1.9	00	0	0	0	0	649	0	0	430	2.65	7.93	10	7.9	21.5
	Below	7-25	1	2.1	2.1	00	12	0	0	0	222	0	3	-	-	-	-	7.8	22.0
West Liberty		7-24	1	.31	.23	00	0	0	12	0	90	3	0	-	-	-	-	7.8	25.0

TABLE 2

LITTLE MIAMI RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD	D O	pH	Temp.
Beechmont		5-5		Ave.	4.0	.77	.86	517	86	791	11	335	80	32	3155	5.53	6.25	7.6	17.1
		to	14	Max.	14.7	2.0	4.3	2302	196	6724	40	1720	304	64	1100	13.62	12.50	7.8	25.5
		11-20		Min.	.75	.13	.02	0	0	54	0	0	0	0	91	1.63	1.53	7.5	0.0
Milford	14.2																		
Above		11-20	1		6.0	5.9	.04	88	24	12	0	444	0	8	24	1.32	11.84	8.0	7.0
	13.5	7-18		Ave.	1.8	1.1	.21	34	65	164	7	1101	24	21	158	1.70	7.54	-	24.0
Milford		to	3	Max.	3.7	2.6	.36	88	116	324	20	3136	32	40	230	1.87	8.00	-	26.5
		8-15		Min.	.76	.29	00	7	20	44	0	63	0	0	93	1.41	7.10	-	22.5
Milford	13.3	8-28		Ave.	2.3	.73	.27	449	39	951	11	103	46	24	54	2.43	9.51	8.1	16.5
Below		to	3	Max.	2.6	2.0	.65	748	60	2262	24	304	76	30	93	3.09	11.58	8.2	23.5
		11-20		Min.	2.2	.05	.02	117	24	44	0	0	0	8	23	1.32	7.98	8.0	6.0
Loveland	24.6	7-17		Ave.	4.1	.74	.80	262	100	1239	6	131	85	8	19.4	2.71	10.06	8.0	18.3
Above		to	4	Max.	7.4	1.5	1.7	480	296	2934	24	372	171	12	36	4.48	12.20	8.1	24.0
		11-20		Min.	1.5	.07	.10	48	28	68	0	12	7	2	.73	1.73	7.90	7.9	6.5
Loveland	23.6	7-17		Ave.	3.6	1.7	.30	191	77	474	4	466	36	12	24.8	1.97	10.18	8.1	18.2
Below		to	3	Max.	4.7	4.2	.37	432	159	924	12	1169	60	20	36	3.12	11.90	8.1	25.0
		11-20		Min.	2.4	.15	.26	12	24	68	0	6	8	4	2.3	1.06	7.93	8.0	7.0
Kings Mills	31.2	8-2		Ave.	2.0	.71	.58	111	46	456	8	132	64	18	14.7	1.46	9.09	8.0	19.3
		to	4	Max.	4.4	2.0	.25	160	96	1620	4	232	112	52	36	1.82	11.34	8.1	24.5
		11-22		Min.	.62	.21	00	60	12	44	0	8	1	4	4.3	1.03	7.83	7.9	6.5
S.Lebanon	33.8	8-2		Ave.	2.1	.27	.79	153	75	272	0	57	81	8	45	1.32	7.85	7.9	25.0
		to	3	Max.	4.9	.43	1.8	264	174	724	0	148	112	20	91	1.58	8.17	7.9	28.5
		9-27		Min.	.47	.11	.16	4	12	36	0	0	64	4	9	1.05	7.40	7.9	23.0
Yellow Springs		8-25		Ave.	.92	.50	.04	8	7	79	0	29	4	3	19.6	0.82	8.53	7.8	13.8
Above	82.0	to	4	Max.	1.4	1.3	1.05	16	16	228	0	72	12	8	46	0.99	10.07	8.1	21.5
		11-17		Min.	.10	00	.01	0	0	4	0	0	0	0	.91	0.61	7.37	7.6	7.0
Yellow Springs		9-22		Ave.	3.2	.10	.19	11	12	165	0	40	10	7	9.74	0.88	10.53	7.9	9.5
Below	81	to	3	Max.	9.2	.16	.48	12	16	474	0	62	28	12	24	1.26	12.98	8.0	14.0
		11-17		Min.	.19	.05	.05	8	0	0	0	16	0	0	.91	0.54	8.48	7.9	4.5
S. Charleston	96.5	9-7			.94	.62	.26	28	56	24	0	192	24	8	36	1.53	6.55	7.9	19
	96.5	10-4			35.9	1.2	31.2	0	4	15	0	636	2830	0	110	5.53	9.50	8.3	20.5
	99	9-7			2.2	2.0	.08	16	0	24	16	610	30	12	150	4.35	3.95	7.9	18.0
	99	10-4			.74	.66	.06	0	0	16	4	136	72	0	460	2.49	7.53	7.9	18.

EAST FORK

Station	Mile	Date 1939	No. of Samp.		Volume T	I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD	D O	pH	Temp.
South Milford		7-18		Ave.	1.5	.51	.28	1452	82	183	0	46	145	6	37.5	2.04	7.81	7.6	19.3
		to	5	Max.	3.3	1.4	.90	6492	268	336	3	51	446	15	73	2.40	11.24	7.7	23.5
		11-21		Min.	.14	.02	00	36	4	20	0	4	16	0	1.5	1.80	5.63	7.6	7.5
Batavia		7-31		Ave.	2.61	.28	1.33	1651	133	59	5	28	140	35	162	2.88	5.46	7.5	16.3
Below		to	3	Max.	7.1	.56	2.0	2360	356	20	8	80	356	44	430	3.84	7.02	7.5	23.5
		11-21		Min.	.29	.02	1.8	40	0	4	0	0	16	24	9	1.37	4.43	7.5	6.5
Williamsburg		6-30		Ave.	1.2	.73	.5	1220	80	247	2	23	106	28	16	2.42	7.98	7.6	18.3
Above	46.2	to	4	Max.	3.9	1.4	1.7	2927	144	568	8	48	240	100	36	3.53	10.37	7.7	25.0
		11-21		Min.	1.6	.08	.21	40	24	22	0	0	0	0	2.4	0.66	6.52	7.5	6.5
Williamsburg		6-30		Ave.	1.7	1.3	1.	535	330	314	0	36	96	15	341	3.99	6.85	7.5	19.3
Below	45	to	5	Max.	8.9	5.0	2.9	2236	1344	716	0	84	388	28	1100	10.98	7.52	7.6	25.0
		11-21		Min.	.44	1.03	.36	12	24	132	0	0	8	8	36	1.45	6.16	7.4	6.0
Lynchburg Above		10-9	1		1.7	.1	.55	1106	4	24	0	8	152	32	23	3.50	2.53	7.7	20.0
Below		"	1		.37	.01	.19	112	4	16	0	0	72	12	4.3	3.18	5.56	7.8	21.0

TABLE 2, cont.

TURTLE CREEK

Station	Mile	Date 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD	D.O.	pH	Temp.
South Lebanon		7-19		Ave.	26.2	.30	.73	50	61	618	0	99	23	28	135	3.02	7.00	7.9	20.0
	34.2	to	3	Max.	77.3	.72	.38	100	92	1716	0	330	32	76	230	5.37	7.27	7.9	22.5
		9-27		Min.	.35	.07	.02	3	28	72	0	12	8	0	24	1.22	6.60	7.9	16.5
Lebanon		7-19		Ave.	5.5	1.5	.98	291	850	641	0	220	122	30	84	2.30	6.35	7.5	16.8
Above		to	5	Max.	18.3	3.5	2.3	760	3964	3592	3	844	464	52	230	4.62	8.00	7.6	21.5
		11-22		Min.	1.0	.60	0	6	0	32	0	4	12	8	2	1.33	5.42	7.5	8.0
Lebanon		7-19		Ave.	1.3	.44	.56	6	[illegible]	45	11	140	29	66	43,000	25.04	2.44	7.5	17.1
Below	37.8	to	4	Max.	2.4	1.6	1.6	16	3	87	24	495	44	208	150000	79.30	4.70	7.5	21.5
		11-22		Min.	.37	.03	0	0	0	8	0	16	16	4	2400	2.32	0.00	7.5	7.0
CAESAR CREEK																			
Jamestown		8-14		Ave.	2.8	1.2	.53	6	20	212	28	406	176	336	568	5.89	3.25	7.5	20.0
Above	78.5	to	2	Max.	4.3	1.8	.65	8	40	336	56	608	292	668	1100	8.70	3.42	7.5	23.0
		8-25		Min.	1.3	.65	.40	4	0	8	0	204	60	0	36	3.07	3.07	7.5	17.0
Jamestown		8-14		Ave.	2.4	.5	1.1	0	6	164	0	163	180	2	345	5.12	2.50	7.7	20.3
Below	76.5	to	2	Max.	2.6	.86	1.2	0	12	320	0	280	252	4	460	5.28	3.14	7.7	22.5
		8-25		Min.	2.2	.14	.88	0	0	8	0	45	72	0	230	4.95	1.85	7.7	18.0
SHAWNEE CREEK																			
Xenia	80.6	6-29		Ave.	2.9	.62	2.0	4	7	63	2	149	58	6	217	1.52	7.03	8.0	16.8
Above		to	7	Max.	12.0	1.9	10.8	20	40	144	8	444	304	20	1100	2.91	11.34	8.1	24.5
		11-17		Min.	.34	.02	0	0	0	0	0	12	0	0	4.3	1.01	4.46	7.8	6.5
Xenia	76.1	6-29		Ave.	.98	.52	.05	5	0	98	0	185	12	1	3147	4.71	4.17	7.5	14.9
Below		to	4	Max.	2.0	1.8	.13	12	0	368	0	640	38	3	11000	5.38	7.27	7.6	21.5
		11-17		Min.	.11	.07	00	0	0	0	0	28	0	0	43	3.69	2.44	7.3	7.5
Xenia	76.1	7-17		Ave.	2.2	.86	1.1	1	3	33	13	176	18	5	8420	6.55	5.76	7.9	15.7
Below		to	6	Max.	8.4	2.6	5.4	4	12	88	36	944	48	16	46000	7.83	6.53	8.0	23.5
		11-17		Min.	.48	.08	00	0	0	0	0	36	0	0	240	5.61	3.87	7.7	8.0
LYTLE CREEK																			
Wilmington		6-29		Ave.	3.3	1.0	1.3	10	45	111	[illegible]	127	56	21	689	3.19	5.62	7.5	20.2
Above	66.5	to	6	Max.	7.4	2.0	4.3	40	224	504	4	284	222	72	2400	8.94	9.08	7.5	24.5
		10-2		Min.	.25	.16	0	0	0	12	0	32	16	0	91	1.04	0.51	7.5	15.0
Wilmington		6-29		Ave.	3.2	1.4	.05	7	16	231	[illegible]	413	73	6	1116	6.71	8.08	8.0	20.9
Below	59.5	to	6	Max.	4.7	3.8	1.6	20	92	856	4	760	276	12	4600	23.40	12.90	8.2	25.5
		10-2		Min.	.92	0	0	0	0	24	0	32	21	0	36	1.32	0.21	7.7	13.5

TABLE 3
LICKING RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli.	BOD.	D.O.	Tby.	pH	Temp.
Latonia	5.5	5-3		Ave.	.99	.15	.14	453	22	192	0	543	17	12	157.2	1.56	8.34	-	7.66	18.6
		to	9	Max.	3.1	.28	.39	3472	71	704	0	4526	54	44	1100.0	2.13	11.40	-	7.8	26.0
		11-13		Min.	.18	.02	00	0	0	24	0	4	0	0	2.3	0.97	6.50	-	7.5	5.0
Falmouth	51.5	5-3		Ave.	.64	.09	.15	36	14	93	0	26	20	4	73.9	1.52	7.58	-	7.8	21.2
		to	7	Max.	2.45	.23	.67	97	28	320	4	76	68	12	460.0	2.03	9.55	-	7.8	26.0
		9-18		Min.	.22	.01	00	2	0	20	0	0	2	0	2.3	1.01	7.58	-	7.8	15.5
Claysville Above	83	9-18	1		.33	.02	.01	8	20	80	0	0	12	0	46.0	1.71	8.48	54	7.9	26.0
Blue Lick Above	100	9-18	1		.38	.04	.02	104	4	68	0	8	40	12	2.3	2.32	5.92	32	7.5	23.5
Below	96	9-18	1		.10	00	.04	32	0	16	8	0	20	4	2.4	1.33	6.27	37	7.4	23.5
Flemingsburg Below		9-19	1		5.1	.04	3.0	0	48	124	28	0	2184	20	150.0	7.96	5.90	36	7.8	20.0
Morehead Below		9-19	1		9.1	.68	1.1	1172	604	4	0	0	4144	8	23.0	3.30	2.16	11	6.9	20.5
SOUTH FORK																				
Falmouth		5-9		Ave.	3.3	.21	1.37	23	79	585		21	126	7	67.7	2.17	7.87	-	7.8	23.5
		to	8	Max.	13.8	.67	7.2	84	180	1752	12	103	666	16	240.0	3.31	9.64	-	-	27.5
		9-18		Min.	.44	.02	.07	0	0	28		0	5	0	2.3	1.14	6.92	-	-	20.0
Farmers	170	9-19	1		.56	.08	.10	1168	20	44	4	0	12	4	3.6	0.63	6.49	14	7.3	20.5
Lair Above		9-13	1		2.9	1.09	.34	156	72	2716	0	4	109	8	3.6	2.15	5.44	76	7.9	21.5
Below		9-13	1		3.6	.04	.89	160	32	1780	0	0	163	76	3.6	1.63	6.70	76	7.8	24.5
Cynthiana Above		9-13	1		.85	.06	.23	80	36	380	0	8	84	4	23.0	1.53	4.24	39	7.6	22.0
Below		9-13	1		4.7	.04	2.4	12	36	120	0	40	308	8	2.0	2.99	12.67	22	8.6	25.5
Paris Above		9-12	1		3.1	.00	1.3	0	36	560	0	0	104	16	3.6	1.49	6.87	12	7.8	24.5
Below		9-12	1		23.4	.50	.83	0	240	892	0	13	76	22	36.0	5.30	5.06	30	7.8	20.5
Below		9-22	1		17.4	.17	7.8	0	184	524	0	0	2206	12	46000.	41.15	0.0	51	7.4	22.0
Mt. Sterling Above		9-12	1		.24	.02	.0	45	0	132	4	4	0	0	36.0	5.39	9.10	80	7.9	20.5
Below		9-22	1		.11	00	.01	4	0	20	0	0	12	0	110000.0	41.07	0.00	28	7.5	15.5
STRODES' CREEK																				
Winchester Above		9-12	1		.11	.01	00	128	4	4	0	0	8	4	36	3.03	4.11	20	7.6	16
Below		9-22			.12	.10	.02	8	4	16	0	32	4	0	3.6	3.12	3.55	17	7.6	22
BRUSH CREEK																				
Carlisle Below		9-13	1		.15	00	.07	4	0	12	0	4	16	0	23.	1.52	7.37	15	7.6	25.0

TABLE 4

KENTUCKY RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B.coli	BOD.	D.O.	Tby.	pH	Temp.
Carrollton		5-2 to 11-30	21	Ave.	1.3	.26	.06	16	25	146	4	114	17	9	4.41	1.52	7.39	47	7.6	20.4
				Max.	10.2	1.4	.46	100	116	1256	44	540	140	24	11.0	3.39	9.90	340	8.1	26.
				Min.	.13	.01	00	0	0	0	0	12	0	0	0.39	0.63	5.41	6	7.3	9.
Gratz	29	8-21	1		1.6	.08	.06	8	64	176	0	48	17	0	-	-	-	-	6.9	26.
Frankfort																				
4 mi. Below	63	9-27	1		1.6	1.1	00	8	8	36	8	87	4	64	93.0	2.57	3.39	18	7.3	23.5
Dam	65	9-27	1		1.3	1.3	00	0	4	14	4	2098	0	24	240.0	2.40	6.56	13	7.8	23.5
1 mi. Above	66	9-27	1		.92	.89	00	0	20	12	0	1542	4	4	43.0	2.05	8.74	15	8.1	24.
Camp Nelson	135	9-28	1		.99	.50	00	0	548	96	4	24	0	8	3.6	1.83	7.64	12	7.7	23.
Irvine	217.1																			
Below		9-29	1		.09	.01	.04	96	0	0	0	0	24	0	9.3	1.88	5.71	-	7.2	25.
Ravenna	221																			
Above		9-29	1		1.2	.72	.16	1128	4	20	0	0	30	8	2.3	2.95	7.40	-	7.1	24.5
Beattyville	254.8																			
Above		9-29	1		.34	.03	.19	425	0	0	0	0	60	4	240.0	2.06	7.46	-	7.3	25.
Below		9-29	1		.24	.04	.07	332	4	48	0	0	45	0	9.3	2.21	6.71	-	7.2	24.5
Jackson	305																			
Above		10-17	1		.12	.02	00	276	4	4	0	0	0	4	9.3	1.51	10.33	16	7.5	11.5
Below		10-17	1		.45	.13	.26	1082	36	16	12	0	35	12	3.6	3.25	7.97	34	7.6	11.5
Chavies	335.8																			
		10-17	1		.14	.07	.07	1124	8	0	0	0	4	0	0.9	1.91	10.96	-	7.6	17.
Hazard																				
Above		10-16	1		.41	.29	00	1380	28	28	4	0	12	8	46.0	2.26	9.23		7.7	9.
At		10-16	1		1.24	.19	.03	800	12	4	20	0	16	4	150.0	1.62	7.89	17	7.4	9.5
Below		10-16	1		.12	.05	.05	240	0	4	24	0	8	0	4600	8.82	3.31	13	7.3	8.5
Whitesburg	404																			
Above		10-19	1		.01	00	00	4	0	0	0	0	8	0	9.3	0.98	9.84	5	7.9	10.
Below		10-19	1		.27	.20	.02	0	0	0	0	68	0	28	460.0	1.36	5.07	14	7.7	11.
SOUTH FORK																				
Manchester	299																			
Above		10-16			.21	.03	00	320	4	0	8	0	88	4	9.3	1.67	6.68	12	7.2	13
Below		10-16			.54	.11	.04	130	112	92	0	0	4	16	93.	1.91	4.52	5	7.2	9
Big Creek	299	10-6			1.7	1.3	.06	2593	8	64	0	0	48	32	.36	1.60	8.78	28	7.3	11
Jackson a	310.4	10-17			1.4	.27	.24	1200	96	20	0	48	36	22	240.	1.88	9.85	12	7.2	11
Hyden b	327.6	10-16			.02	00	00	36	0	8	0	0	0	8	7.3	.86	9.17	11	7.3	10.5
Blackey	387.6	10-20			.01	00	00	60	0	4	0	0	0	0	24	0.78	10.10	5	7.5	14.5
Neon		10-18			.85	.70	.03	28	0	36	8	276	8	4	240	3.03	8.31	14	7.9	12
Cornettsville		10-20			.12	.07	00	594	40	12	0	0	12	0	9.3	1.78	6.60	8	7.3	10.5
Haddux	314	10-17			.02	.01	00	188	0	0	0	0	0	4	4.3	0.96	10.0	15	7.8	12

a = above b = below

TABLE 5

BIG SANDY RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B.coli	BOD.	D.O.	Tby.	pH	Temp.
Dam 1	.3	6-14		Ave.	1.0	.07	.61	36	98	147	3	43	65	10	117.	1.36	6.72	44	7.5	24.1
		to	18	Max.	3.0	.28	2.3	213	336	512	9	200	292	32	460	2.09	8.88	250	7.8	29.
		11-27		Min.	.13	.01	00	0	0	0	0	0	0	0	7.5	0.77	4.85	5	7.1	10.
Dam 3	26.6	6-14		Ave.	.27	.14	.09	94	54	21	0	10	13	13	140.	0.89	7.84	8	7.7	24.9
		to	7	Max.	.77	.32	.21	296	328	56	4	30	26	16	240	1.14	8.20	12	8.0	29.
		10-13		Min.	.08	.01	00	0	0	0	0	0	0	0	3.6	0.53	7.39	6	7.0	19.5
TUG FORK																				
Dam 1	3.8	10-13	1		.11	.03	00	32	0	4	0	18	0	0	4.3	0.96	9.08	-	-	14.
Kermit Above		11-24	1		.29	.02	.12	248	8	48	0	0	0	4	2.3	2.48	10.81	5	7.8	6.
" Below	35.5	11-24	1		.17	.05	00	272	28	32	0	4	0	0	36.	1.87	10.77	5	7.6	6.5
Williamson																				
Above	57.1	11-19	1		.66	.66	00	140	4	40	0	16	0	12	3.6	0.82	11.56	5	7.8	7.
Below		11-8	1		.25	.05	.20	60	52	12	0	0	0	12	1100.	1.58	8.94	5	7.7	8.
Matowan	98	11-24	1		.18	.02	00	80	12	44	0	12	0	0	4.3	1.97	11.54	5	7.7	6.5
Iaeger Above	136	11-20	1		2.5	2.0	00	0	4	32	0	304	0	0	4.3	2.48	11.86	7	8.4	7.5
" Below		11-20	1		2.0	1.95	.02	12	8	12	0	536	0	4	1100.	3.18	12.42	5	8.4	8.
Welch Above	159	11-9	1		.53	.53	00	8	0	0	0	204	0	0	9.3	2.60	14.78	5	7.5	9.
Below		11-9	1		.50	.10	.40	0	0	0	0	40	0	44	460.	11.40	8.79	18	8.1	11.5
Gary	168	11-9	1		.02	.02	00	0	0	0	0	8	0	0	240.	5.76	11.26	5	7.6	9.
LEVISA FORK																				
Louisa		9-29	1		.27	.04	.12	420	0	260	0	0	4	32	0.9	0.54	7.80	-	-	22.5
Wallbridge	2.7	10-13	1		.42	.30	00	592	0	124	0	48	0	0	4.3	0.95	6.68	-	-	17.5
Paintsville																				
Above	38.6	11-28	1		.25	.05	.20	384	24	0	0	0	0	12	7.5	1.27	11.33	7	7.4	4.
Below		11-28	1		.04	.04	00	304	4	0	0	8	0	0	240.	1.70	10.98	12	7.3	4.
Van Lear		11-29	1		.46	.17	00	740	124	24	0	4	0	8	0.4	1.86	12.01	11	7.3	3.5
Prestonburg Above		11-24	1		1.4	.29	1.0	1398	228	12	0	0	4	20	3.6	1.55	10.80	17	7.2	7.
Below	54.9	11-24	1		.22	.19	00	948	148	8	0	0	0	0	150.	1.57	10.61	20	7.1	7.
Boldman b	77.3	11-9	1		.18	.11	.05	784	68	8	0	4	4	8	3.6	3.39	13.41	16	7.9	12.
Pikeville a	88.5	11-9	1		.29	.27	00	3552	32	4	0	4	5	4	3.6	0.56	11.27	18	7.3	5.
" b		11-9	1		1.9	.41	1.4	4040	132	12	0	32	8	24	1100.	3.58	8.62	12	7.2	8.
Millard a		11-6	1		.64	.47	.09	1010	76	0	0	8	16	8	3.6	1.45	10.73	30	7.2	5.5

Station key: a - above b - below

TABLE 6

LITTLE SANDY RIVER

Station	Mile	Date 1939	No. of Samp.		T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B.coli	BOD.	D.C.	Tby.	pH	Temp.
Greenup	.1	6-14		Ave.	.29	.08	.11	61	37	18	0	13	6	8	167.2	0.95	7.35	43	7.4	21.1
		to	18	Max.	1.5	.66	1.2	146	264	40	4	52	36	24	1100.0	1.47	9.90	160	7.9	25.5
		11-24		Min.	.02	00	00	0	0	0	0	0	0	0	3.6	0.54	6.26	6	7.2	6.5
Grayson Above	24.	9-8		Ave.	.09	.04	.03	404	5	0	0	4	3	9	14.1	0.90	6.63	25	7.6	14.5
		to	4	Max.	.19	.07	.12	896	20	0	0	12	10	16	24.0	1.11	7.10	30	7.8	22.0
		11-29		Min.	.06	.01	00	0	0	0	0	0	0	0	9.1	0.58	6.29	22	7.5	3.0
Grayson Below		9-8		Ave.	.30	.06	.22	382	4	6	0	0	17	14	460.0	1.43	5.71	31	7.6	14.4
		to	4	Max.	.66	.14	.50	860	9	12	0	0	37	32	460.0	2.24	6.50	35	7.9	22.0
		11-29		Min.	.01	.01	00	10	0	0	0	0	0	0	460.0	0.77	4.74	22	7.3	3.0

TABLE 7

GUYANDOT RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B.coli	BOD.	D.O.	Tby.	pH	Temp.
Huntington		6-14		Ave.	.37	.11	.05	53	15	67	2	25	6	2	2087.	2.40	6.25	41	7.3	22.
		to	16	Max.	1.4	.65	.24	316	108	260	8	180	40	8	11000.	7.64	10.68	210	7.5	28.5
		11-27		Min.	.06	00	00	0	0	4	0	0	0	0	91.	0.90	0.08	5	6.7	7.
Chapmanville	69	12-1	1		.36	.02	00	212	4	80	0	0	0	12	30.	1.57	10.97	5	7.4	8.
Henlawson	76.8	11-28	1		.07	.04	00	392	4	8	0	4	0	0	43.	2.38	7.49	32	7.1	8.
Logan																				
Above		11-30	1		.08	.02	00	1156	0	0	0	0	8	0	75.	1.58	12.63	3	7.6	4.5
Below	81.4	11-28	1		.08	.08	00	1008	20	0	0	0	0	0	91.	1.86	8.11	20	7.1	9.
Man																				
Above		11-27	1		.11	.11	00	1580	0	0	0	4	0	0	3.6	1.96	13.31	8	7.9	5.5
Below		11-27	1		.23	.22	00	718	0	8	0	72	0	0	7.2	2.96	13.69	2	7.9	6.5
Gilbert	111	10-10	1		.02	.02	00	88	0	0	0	4	0	0	-	-	-	-	7.6	24.
Pineville																				
Below	143	11-13	1		.02	.02	00	0	0	0	0	36	0	4	430.	3.20	10.89	5	7.7	3.5
Itman	153.6	11-13	1		.42	.42	00	0	2	1	0	630	0	0	460.	4.51	10.59	2	7.7	2.5
Mullens																				
Above	157.6	11-13	1		.24	.24	00	0	0	0	0	96	0	0	-	4.51	10.59	2	7.7	3.
Below	156.0	11-13	1		.01	00	00	4	4	0	0	0	0	0	43.	3.64	9.28	7	7.7	3.

TABLE 8

KANAWHA RIVER

Station	Mile	Date 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Mxy.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
Pt. Pleasant	.6	8-10 to 11-27	7	Ave.	.68	.19	.29	55	182	61	0	278	6	6	1.6	0.78	7.34	7	7.3	18.1
				Max.	3.7	1.0	2.0	108	1112	244	4	864	36	24	4.3	0.89	8.53	12	7.6	27.
				Min.	.07	00	00	0	4	0	0	0	0	0	0.4	0.69	6.24	4	6.9	5.
Buffalo	21.8	7-6	1		.60	.42	.02	32	460	108	0	8	0	4	-	-	-	-	-	-
Winfield	31.1	8-10	1		1.1	.15	.84	112	160	52	0	4	12	40	-	-	-	-	6.8	26.
St. Albans Below	46.2	7-4	1		1.1	.03	.05	36	0	216	0	36	20	0	-	-	-	-	6.9	26.
Cheylan	73.7	7-4	1		.03	.01	00	0	0	28	0	8	8	0	-	-	-	-	7.1	29.
Montgomery	85.6	7-4	1		.15	00	00	0	0	60	0	0	0	0	-	-	-	-	7.1	-

TABLE 9

MONONGAHELA RIVER

Station	Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.
Dam #2	11	8-19	.25	00	00	0	0	290	0	0	0	0	.91	0.65	5.38	3.5	19
Dam #4	41	8-19	.60	00	00	0	0	780	0	0	0	0	.73	0.85	7.21	3.3	26
Dam #5	56	8-19	.38	00	00	0	0	472	0	0	0	0	2.1	0.54	7.30	3.7	26
Dam #6	68	8-19	.02	.02	00	5	5	0	5	85	0	0	.36	0.33	7.18	3.3	26.5
Dam #7	84	8-19	.30	.02	.06	0	0	275	0	5	5	0	.36	0.66	7.52	3.4	26
Dam #8	90	8-19	.22	00	00	0	0	280	0	0	0	0	.36	0.52	7.33	3.3	26.5
TRIBUTARIES TEN MILE CREEK																	
Mariana	a	8-21	.84	.23	.42	20	240	30	0	10	380	0	23	1.19	6.67	7.6	20.5
"	b	8-21	1.3	.45	.22	40	285	65	0	85	250	40	1100	2.95	6.66	7.5	20.5
Waynesburg	b	8-21	1.9	1.2	.27	55	875	40	40	2015	90	15	110000	9.18	0.44	7.4	22
Waynesburg	a	8-21	18.1	.74	.96	135	15	40	5	1395	320	4825	93	1.59	5.97	7.6	20.5
PIGEON CREEK																	
Bentleyville North Fk.		8-21	.04	00	00	0	0	5	0	0	15	0	3.6	0.47	7.84	6.6	15
Bentleyville At		8-21	5.5	1.4	3.1	175	135	135	0	845	470	10	1100.	2.49	8.35	7.6	17.5
Bentleyville Below		8-21	3.3	2.0	.85	15	115	35	5	1520	220	10	240	1.91	8.67	7.5	15.5
Cokeburg		8-21	2.8	2.2	.45	0	35	0	0	745	215	0	240	2.03	8.58	7.6	17.0
Ellsworth		8-21	.71	.28	.12	5	40	25	0	125	30	10	9.1	1.85	4.37	7.5	18.5
Youghiogheny River McKeesport		8-19	1.1	00	1.1	0	0	0	0	0	20	95	2.3	1.43	6.18	3.5	25

Station Key: a = above; b = below.

TABLE 10

ALLEGHENY RIVER

Station	Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.
Dam #2	6	8-20	.06	.03	00	0	0	30	0	10	0	0	2400	1.54	6.82	6.6	27
Dam #3	14	8-20	3.2	3.2	00	0	0	0	0	49	0	0	.36	0.78	6.80	4.4	28
Dam #4	24	8-20	x00	x00	00	0	0	0	0	0	0	0	.36	0.45	7.00	4.3	25.5
Mosgrove	50	8-6	2.1	1.8	.09	20	0	65	0	175	5	0	-	-	-	-	27
Dam #8	52	8-20	.64	.39	.06	25	15	70	5	145	10	5	3.6	1.42	8.10	7.4	25.5
East Brady	70	8-2	2.2	2.0	.19	0	0	55	0	80	6	6	-	-	9.67	7.4	27
Parkers Landing	83	8-5	.64	.62	00	0	0	55	0	60	0	0	-	-	10.13	7.3	27
Kennerville	110	8-5	.12	.09	00	0	0	18	6	30	0	0	-	-	-	-	27
Tionesta b	150	8-1	1.6	1.0	.06	40	0	150	15	360	15	5	-	-	-	-	-
TRIBUTARIES																	
STONY CREEK																	
Hooverville a		7-17	.37	.35	00	0	0	5	0	115	0	0	110	0.57	8.95	5.2	18
Holsopple b		7-17	.09	.02	00	18	0	6	0	6	0	0	3.6	0.36	8.71	4.7	19.5
KISKIMINETAS RIVER																	
Freeport		8-20	.57	.07	00	10	0	50	5	175	10	25	3.6	1.56	7.46	7.4	25
RED BANK RIVER		8-6	.15	.11	00	144	0	16	0	48	0	24	-	-	-	-	-
CLARION RIVER																	
Cooksburg		8-3	1.6	1.3	.10	8	0	48	8	144	0	16	-	-	-	-	24

a = above; b = below

TABLE 11
MUSKINGUM RIVER

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.	Tby.
Dam #1	0.2	6-28	.48	.10	00	5	00	45	0	85	5	5	-	-	-	-	22.5	
Dam #1	0.2	7-10	1.2	.09	00	70	15	225	0	250	25	10	-	-	-	-	23.5	
Dam #1	0.2	7-15	4.5	2.1	1.4	215	40	210	25	405	30	25	-	-	-	-	-	
Beverly	a 24	8-8	.59	.55	00	35	0	59	6	145	6	0	-	-	-	-	29	
Stockport	39	7-19	5.1	3.4	.01	295	50	250	0	1230	30	35	-	-	-	-	-	
McConnelsville	49	7-19	6.8	4.0	.76	370	60	395	0	840	50	50	-	-	-	-	-	
McConnelsville	a 50	8-8	1.4	.50	.55	810	35	150	5	170	15	25	-	-	11.39	7.3	28	
Gaysport	61	7-19	7.2	3.9	.65	270	170	740	0	945	95	261	-	-	-	-	-	
Duncan Falls	67	5-7	.14	.13	00	66	15	6	0	560	0	0	9.1	1.94	9.79	7.5	16	38
Duncan Falls	67	7-19	10.1	4.6	3.0	445	215	680	0	735	105	45	-	-	-	-	-	
Duncan Falls	67	8-9	2.5	1.1	.41	380	25	375	15	445	55	20	-	-	-	-	27	
Zanesville	70	5-7	.45	.44	00	176	4	4	0	1452	0	0	3.6	2.15	9.84	7.4	15.5	
Zanesville	b 70	6-7	1.9	1.8	00	170	24	24	0	3808	8	8	-	-	-	-	15.5	
Zanesville	75	7-17	9.8	3.8	.66	590	115	790	5	440	60	25	-	-	-	-	-	
Zanesville	b 70	7-19	5.3	1.3	1.2	845	115	795	10	765	70	30	-	-	-	7.5	14.5	
Dam #11	84	5-9	1.7	1.6	00	212	0	24	0	600	4	0	4.3	1.75	8.31	7.5	14.5	
Dresden	a 91	4-30	.25	.15	19	105	0	5	0	10	5	0	3.6	0.82	9.68	7.6	15.5	
Dresden	b 91	4-30	1.0	.94	00	165	0	20	0	15	0	0	36	2.79	9.78	7.6	15	115
Coshocton	b 110	5-8	.28	.23	00	232	4	16	0	72	0	4	-	1.72	8.55	7.5	15.5	32

TRIBUTARIES
TUSCARAWAS RIVER

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.	Tby.
Coshocton	a 115	5-8	.17	.10	00	124	8	16	4	8	4	0	-	-	-	-	17.5	
W.Lafayette	a 120	5-8	.03	.01	00	36	4	8	0	4	0	0	46	2.29	8.41	7.4	18.5	
Newcomerstown	b 125	5-18	.14	.4	0	276	4	12	0	220	12	0	93	1.43	8.88	7.4	18.5	
Newcomerstown	a 135	5-10	.23	.2	00	240	12	12	0	28	4	0	24	1.17	8.39	7.2	18.5	
New Phila.	b 160	5-23	6.4	6.1	.20	44	4	20	4	3144	20	0	240	1.81	8.90	7.5	19.5	
Dover	a 170	5-23	4.6	4.5	.05	278	8	16	0	2500	32	0	93	2.00	9.26	7.8	19	
Barberton	a 225	5-22	1.2	.70	.07	968	52	272	8	368	76	16	1100	7.29	5.75	8.4	22	
Jonathon Creek		6-10	.30	.16	.10	4	4	40	0	556	8	0	-	-	-	7.7	26	
Mohican River		7-19	5.4	2.4	1.08	8	0	1200	80	130	226	88	-	-	-	7.9	27	
Killbuck River 5 mi.above mouth		7-19	1.8	.94	.77	0	70	10	5	195	85	0	-	-	-	-	-	

LICKING RIVER

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.	Tby.
Newark	b	5-1	.20	.19	00	4	0	16		160	0	0	240	3.20	8.34	7.6	15	
Newark	a	5-2	1.1	.07	00	55	15	15		255	5	0	4.3	2.78	9.40	7.7	10.5	
Utica	b	4-30	.31	.26	00	4	0	0		52	0	4	430	1.73	9.65	7.7	15	
Utica 1.5 mi. above		4-30	2.5	2.5	00	15	0	0		100	0	0	9.3	1.20	9.80	7.8	14.5	
Utica at		4-30	.29	.24	00	36	8	12		48	0	0	15	1.40	9.5	7.8	14.5	

LICKING RIVER TRIBUTARY
RACCOON CREEK

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.	Tby.
Johnson	a	4-30	1.9	1.9	00	0		0		64	0	0	9.3	1.23	9.36	7.7	13	
Johnson	b	4-30	1.0	1.0	00	0		8		92	0	0	3.6	1.18	9.68	7.7	13.5	
Granville	a	4-30	1.25	1.2	.05	0		0		60	4	0	4.3	1.15	8.55	7.6	14	
Granville	b	4-30	.66	.66	00	16		0		72	0	0	150	2.65	9.49	7.7	13	

Station Key: a - above; b - below

TABLE 12

HOCKING RIVER

Station		Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.
Hockingport		0.1	6-27	.48	.14	.10	30	110	55	0	50	20	5	7.3	0.87	7.83	7.2	22
"		0.1	7-11	4.9	.81	.44	385	5	958	5	250	50	10	0	2.06	9.15	7.4	26.5
"		0.1	8-14	6.2	1.3	1.9	18	12	171	1015	561	48	61	9.3	1.83	7.21	7.7	28
Coolville		5	8-17	.71	.28	.11	102	12	262	89	87	18	6	-	-	8.41	8.0	28
Guysville		20	8-17	3.6	1.5	1.6	150	6	139	24	90	281	0	-	-	9.0	7.9	27.5
Athens	b	36	6-20	2.1	1.1	.37	25	0	140	15	105	65	0	-	-	5.91	7.6	25
Sunday Creek	b	42	8-17	.62	.26	.06	97	200	137	6	18	12	6	-	-	7.22	7.1	27
Nelsonville	b	50	8-16	3.3	.69	1.9	35	666	132	0	24	244	31	-	-	10.04	8.0	26
Nelsonville		50	7-26	.03	.01	.02	28	0	0	2	2	6	0	-	-	7.35	7.4	27
Logan	a	70	7-26	2.6	2.5	.02	0	0	5	10	420	20	0	-	-	7.21	7.5	27

TRIBUTARIES

Station		Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	pH	Temp.
Federal Creek		18	6-10	.60	.53	.07	0	0	0	0	104	12	0	-	-	-	7.5	24
Sunday Creek		43	8-16	.02	.02	00	0	0	6	0	6	0	0	-	-	-	3.0	23.5
" "		43	7-23	.91	.83	00	0	10	3	0	15	0	0	-	-	6.60	3.1	27.5
" "		43	7-25	00	00	00	5	0	5	0	0	0	0	-	-		6.0	
Monday Creek		49	8-16	.09	.09	00	0	0	0	0	30	0	0	-	-	7.07	3.2	27
" "							0	0	0	0		0	0	-	-	-	-	-
" "			7-25	.05	.05	00	0	0	5	0	15	0	0	-	-	-	3.8	-
" "		50	7-23	.09	.09		0	0	0	0	30	0	0	-	-	-	2.8	-
" "		50	7-25	.36	.36	00	0	0	0	0	120	0	0	-	-	-	3.3	-
Little Monday Creek		75	6-6	.09	.09	00	0	5	0	0	85	0	0	-	-	-	6.8	26

Station key: a = above, b = below

TABLE 13

LITTLE KANAWHA RIVER

Station		Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B.coli	BOD.	D.O.	pH	Temp.
Viscose	b	2	8-22	4.6	00	.34	30	0	90	0	0	170	5	-	-	0.33	6.3	26
Viscose	b	2	8-23	2.5	00	.15	0	0	55	0	0	60	0	-	-	0.00	6.1	25
Dam #1	b	3.4	8-23	31.0	00	.01	10	0	710	0	0	125	20	-	-	2.45	6.3	26.5
Dam #1	b	3.4	8-22	13.6	.02	.20	0	0	280	0	5	55	35	2.3	1.50	4.45	6.1	24.5
Dam #1	a	3.5	8-22	19.4	00	00	5	0	450	0	0	25	75	-	-	-	7.2	25
Dam #1	a	3.5	8-23	1.1	00	.04	0	0	45	0	35	20	5	-	-	4.62	7.1	24
Dk 282		5	6-27	.11	.02	00	5	0	15	0	10	5	5	-	-	-	-	22
Hughes Creek		17	8-22	.31	.06	.04	420	0	125	0	10	25	115	-	-	6.40	7.2	23
Elizabeth		25	6-22	1.03	1.03	00	0	0	8	0	16	0	0	-	-	-	-	22.5
Elizabeth	b	26	8-22	1.6	1.2	.15	50	0	95	0	75	260	160	3.6	1.44	7.40	7.2	26
Creston		48	8-21	.75	00	.44	35	0	170	15	5	30	15	-	-	8.20	7.5	26
Grantsville	a	80	8-21	.90	.52	.11	10	0	35	0	10	10	10	-	-	8.80	7.5	26
Grantsville	a	80	8-21	.24	.01	.17	80	0	35	0	0	10	25	-	-	7.50	7.4	24
Glenville	b	101	8-20	1.6	.99	00	165	0	90	10	60	30	0	-	-	6.95	7.1	25
Glenville	a	103	8-20	1.1	.54	00	155	0	40	5	20	10	10	-	-	6.90	7.1	25

Station key: a - above, b - below

TABLE 14
WABASH RIVER

Station		Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
New Harmony	b	40	9-18	2.3	.61	.71	65	0	250	1920	50	30	60	-	-	9.0	--	8.3	26
" "		52	9-4	1.8	1.0	00	110	5	125	1785	10	10	75	5.4	5.12	6.90	10	8.1	25
Grayville		65	9-18	1.7	.01	.40	55	0	465	985	15	30	45	-	-	9.10	-	8.2	24
Mt. Carmel		92	9-18	.8	.03	00	25	0	300	75	50	10	5	-	-	7.05	-	8.1	-
Patton		102	9-17	2.3	1.0	.01	65	0	600	840	15	10	15	-	-	10.10	-	8.5	25
St.Francisville		115	9-17	1.15	.06	.01	130	10	465	435	15	0	55	320	6.20	8.75	20	8.3	24
Vincennes		127	9-4	1.9	.29	00	45	0	715	525	105	0	5	-	-	-	-	-	-
Meron Ferry		165	9-13	4.1	.08	.18	50	0	1995	765	235	15	20	-	-	10.90	-	8.1	22.5
" "		165	9-27	0.9	.16	00	6	0	863	92	56	12	0	15	3.58	7.55	5	7.9	17
Hutsonville Ferry		172	9-27	1.5	.04	00	140	0	871	110	12	18	12	15	3.50	7.44	4	7.9	17
Darwin Ferry		190	8-12	4.9	2.8	00	6	6	1229	137	124	6	6	460	5.80	4.79	5	7.8	27
" "		190	9-27	2.0	.09	.67	237	0	1335	136	25	6	12	580	3.92	3.91	5	7.7	18
Prairieton		205	9-13	1.6	.24	00	20	0	655	80	85	10	20	-	-	3.40	-	7.7	21.5
Terre Haute	b	210	9-13	2.7	.29	00	25	0	1080	260	135	0	0	-	-	3.50	-	7.7	19
" "	b	210	9-26	2.5	.01	1.5	165	0	426	104	0	36	18	96,000	10.6	1.45	10	7.6	16.5
" "	a	220	9-12	3.3	1.3	.06	56	0	860	225	105	15	5	-	-	9.60	-	8.1	19.5
Clinton	a	232	9-25	1.95	1.1	.01	468	43	666	230	436	18	36	7.5	2.86	8.82	15	8.1	17
Hillsdale		238	8-31	14.7	7.2	00	99	118	2475	48	1117	12	56	-	-	-	-	-	23.5
Montezuma		240	9-12	2.6	1.1	.16	40	5	645	145	175	5	0	-	-	8.00	-	7.9	19
Perrysville		264	8-30	5.6	1.5	.01	99	56	1614	61	505	6	67	-	-	-	-	-	25
"		264	9-25	3.2	.38	1.9	865	31	1026	87	130	30	18	23	3.10	8.60	15	8.2	15.5
Covington		269	9-10	1.6	.56	.45	50	0	240	140	240	35	15	-	-	6.90	-	7.7	21
"		269	10-2	0.6	.40	00	300	31	450	12	111	0	24	13	2.79	10.25	40	8.1	14.5
"	a	270	10-2	0.7	.49	00	448	18	729	6	143	0	6	13	3.09	10.26	40	8.1	14.5
Williamsport		287	10-2	0.6	.47	00	398	18	324	0	212	12	0	195	4.02	10.78	23	8.1	16
Attica		288	8-29	11.1	2.5	.01	43	111	2505	149	374	180	62	-	-	-	-	-	-
"	a	289	10-2	2.4	1.9	.10	178	0	714	6	684	18	12	122	3.50	12.12	12	8.2	17
Independence		294	10-2	4.6	3.35	.07	143	25	1003	18	160	49	30	1100	2.76	11.90	12	8.2	18
Lafayette	b	302	10-3	0.9	.51	00	217	0	572	6	160	24	12	670	3.48	9.25	17	8.1	17
Lafayette		312	8-29	3.65	1.6	.10	101	6	1031	67	493	54	36	-	-	-	-	-	25-
Lafayette	a	320	8-29	2.6	1.3	.38	43	18	470	93	506	68	0	-	-	-	-	-	24.5
Delphi	b	330	10-1	4.1	3.1	00	710	56	798	6	179	49	6	43	4.64	14.30	50	8.4	18.5
"		331	9-6	58.3	49.1	4.1	30	483	1819	31	1323	148	61	-	-	9.60	-	8.2	27
"		331	10-1	1.7	.85	.06	886	56	579	0	193	61	61	9.1	4.61	11.37	60	8.4	17.5
Pittsburg		332	8-28	12.3	7.95	1.4	65	78	1417	136	2122	143	60	-	-	-	-	-	-
Georgetown		347	10-3	7.9	4.75	1.1	810	31	958	12	1235	135	66	43	3.95	8.45	45	8.1	16
Logansport	b	353	9-4	11.6	10.3	.69	430	0	295	55	2590	65	0	-	-	14.50	-	8.2	25
"	b	353	9-30	1.6	1.1	.41	265	50	49	0	275	60	0	93	2.92	11.76	15	8.3	17.5
"		355	9-4	12.3	11.4	.43	1390	0	195	5	458	70	0	-	-	10.50	-	8.2	26
"		356	8-27	2.35	.05	.19	50	60	813	155	90	35	15	-	-	11.50	-	8.2	20.5
"	a	357	9-4	2.6	.36	.49	435	0	850	140	270	75	0	-	-	11.40	-	8.2	25
"	a	357	9-30	5.4	2.1	1.2	692	81	643	67	596	192	80	3.6	8.80	13.30	100	8.4	16.5
Peru	b	370	8-1	14.55	13.25	.43	12	0	332	6	3478	96	6	43	3.41	6.98	90	8.1	24.5
"	b	370	8-27	10.9	5.7	2.5	94	264	1053	43	1781	318	31	-	-	-	-	-	-
"	b	370	9-3	2.9	.11	.35	360	0	1305	180	300	65	10	-	-	-	-	-	-
"	a	375	8-1	18.5	16.55	1.1	0	0	322	25	4161	260	6	7.3	3.32	5.50	150	7.9	23.5
"	a	375	9-3	3.6	.24	1.6	125	0	740	170	130	185	20	-	-	12.00		8.2	25
Wabash	b	386	8-2	28.8	24.5	2.85	50	43	560	80	6257	286	55	930	6.27	6.30	45	7.7	23.5
"	a	390	8-2	14.6	9.1	1.7	6	8	927	62	2466	153	49	.91	3.10	6.35	85	8.0	23.5

Station key: a - above; b - below

TABLE 14, cont.
TRIBUTARIES
TIPPECANOE RIVER

Station		Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.C.	Tby.	pH	Temp.
Springboro		8	9-6	.66	.27	.00	0	0	179	0	281	0	7	-	-	9.50	-	8.2	26
"		8	8-28	1.8	.34	.47	0	48	350	210	230	30	5			-		-	
		8	9-7	.58	.15	.05	20	0	110	10	275	15	5			9.25		8.2	25
Monticello		24	8-30	5.80	.56	2.6	87	181	460	205	659	347	-	-	-	-	-		23.5
Buffalo		38	8-28	1.4	.45	.04	12	43	232	6	156	6	0	-	-	-	-	-	
"		38	9-7	.59	.06	.02	15	0	175	5	35	10	0	-	-	7.20	-	8.1	24.5
Pulaski		48	8-28	.97	.39	.03	40	48	210	0	130	20	0	-	-	-	-	-	-
LITTLE WABASH RIVER																			
Emma		25	9-16	5.9	.13	1.4	884	0	215	70	35	320	75	-	-	12.45	-	8.3	23
Carmi	b	41	9-4	.91	.56	.12	64	0	12	4	248	16	64	-	-	-	-	-	22
"	at	42	9-18	1.2	.09	1.0	35	5	30	5	30	0	5	-	-	10.15	-	8.3	27
"	a	43	9-4	11.1	.12	1.0	180	0	3000	5	50	160	75	-	-	-	-	-	22
VERMILION RIVER																			
Grape Creek		19	8-30	3.6	1.6	13	199	111	227	37	941	123	80						22
Danville																			
Below sewage		19	9-11	6.6	1.4	4.5	90	0	240	35	480	420	0	-	-	1.87	-	7.8	21
"	b	19	9-10	9.0	1.9	6.4	40	0	290	30	725	565	15	-	-	2.05	-	7.7	22.5
"		22	8-30	1.4	.63	.20	100	249	204	12	225	90	12	-	-	-	-	-	23.5
"		22	9-11	-	-	-	-	-	-	-	-		-	-	-	9.10	-	-	25
"	a	20	9-11	4.9	1.1	3.3	120	0	135	0	480	340	0	-	-	3.50	-	7.9	23
"	b	14	9-10	3.0	1.3	.49	35	0	305	35	560	100	0	-	-	5.45	-	7.7	20.5
Middle Fork		74	8-30	1.4	.7	.09	154	181	311	0	0	24	6						24
WHITE RIVER																			
Above mouth		3	9-17	1.6	.27	.44	250	5	195	25	85	45	20	2.3	3.95	8.22	-	8.2	24
" "		3	9-5	4.4	3.0	.49	265	50	339	159	110	97	49	8.9	3.85	8.05	25	8.1	25
Hazelton	b	15	9-20	1.4	.58	.21	785	0	210	100	15	55	15	-	-	9.00	-	8.2	26
"	b	15	9-4	4.3	1.4	2.0	204	0	380	124	124	52	36	-	-	-	-	-	23.5
Petersburg	b	47	9-21	1.2	.20	.11	720	5	475	35	70	50	40	-	-	8.50	-	8.1	27
Washington	b	61	9-23	5.6	.94	4.0	965	10	300	50	150	40	125	-	-	6.90	-	8.0	26
Edwardsport		94	9-23	6.6	2.6	2.7	20	65	535	25	3160	45	80	-	-	-	-	-	-
Newberry		116	9-23	12.4	10.2	.34	80	0	847	5	2570	50	10	-	-	11.30	-	8.4	25
Worthington		143	9-24	30.4	28.5	.15	26	37	661	31	6387	30	49	43	7.52	7.98	15	7.9	23
Spencer	b	165	9-24	28.8	24.3	2.3	105	75	1280	61	6112	48	61	93	6.76	11.70	15	8.1	23.5
"		168	9-23	34.5	32.6	.37	5	210	890	15	1618	40	50	-	-	15.65	-	8.3	24
"	a	170	9-24	44.3	38.1	1.6	43	289	3128	61	9540	67	48	15	5.72	9.40	15	8.1	23
Martinsville	at	194	9-3	7.6	2.9	.91	18	118	1997	211	3600	130	0	-	-	8.60	-	8.2	23.5
"	b	190	9-10	5.0	2.7	.16	6	93	1244	0	4562	18	24	460	5.28	9.72	7	8.2	21.5
"		194	9-10	4.2	1.6	.50	6	93	951	42	2096	42	18	2400	5.77	9.90	-	8.1	21.5
"	a	200	9-10	2.7	1.5	.49	0	69	686	12	1437	24	12	2.3	4.46	10.05	7	8.2	21

Station key: a - above b - below

TABLE 14, cont.

TRIBUTARIES

Station		Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
White River, cont.																			
Indianapolis	b	225	9-17	2.0	1.6	.10	6	20	222	0	560	12	0	7.3	7.31	4.45	3	7.7	21
"	b	237	9-17	1.1	.55	.15	0	37	481	0	477	84	0	23	8.33	6.02	8	7.7	24.5
"	b	239	9-17	9.4	1.2	.96	237	493	1634	12	1042	102	18	230	8.29	6.30	-	7.7	25
"	a	257	9-17	11.6	2.8	3.5	206	530	3014	6	16575	215	56	9.3	5.02	12.04	35	6.1	17.5
Noblesville	b	265	9-27	4.4	1.7	.91	54	796	1539	0	6942	27	16	-	-	8.50	-	8.1	15
"	b	265	9-12	35.7	1.8	31.1	400	1740	665	0	1425	1062	115	4.60	7.97	8.59	-	8.1	19
"	a	271	9-12	21.1	1.6	17.8	135	1496	1093	0	1145	1136	24	23	5.70	11.61	23	8.4	18.5
Anderson		297	8-21	4.1	3.0	.1	14	55	294	0	4882	42	6	390	3.99	5.30	55	8.0	21.5
Muncie	b	309	8-21	3.4	.36	1.7	0	0	1667	0	120	136	24	460,000	22.8	0.00	-	7.1	17.5
"	b	310	8-21	.08	.02	00	6	0	200	0	6	0	0	1100,000	59.6	0.00	70	6.1	19.5
"	a	312	8-21	3.5	1.3	1.4	50	81	334	0	49	259	49	46	2.22	9.04	65	8.2	21
Winchester	b	338	8-22	5.5	1.4	3.2	62	305	485	0	80	279	68	46,000	8.25	2.87	17	8.0	19
EAST FORK OF WHITE RIVER																			
Above mouth		51	9-21	.48	.11	.10	160	0	90	70	80	35	10	-	-	7.75	-	8.2	24
Shoals		75	9-3	.74	.05	00	40	5	135	40	5	45	60	.91	-	-	-	-	16
Bedford		93	9-3	.75	.19	00	260	5	400	70	55	5	10	-	-	-	-	-	-
EEL RIVER (White River)																			
Worthington			9-23	.63	.12	.18	1730	0	175	45	10	145	20	-	-	8.45	-	8.1	26
PATOKA RIVER																			
Above mouth			9-17	-	-	-	-	-	-	-	-	-	-	-	-	8.45	-	5.0	21
Below Princeton waterworks			9-20	2.5	.57	.17	40	0	805	100	360	65	0	-	-	9.20	-	6.9	23
Above "			9-20	.23	.04	.17	555	0	0	0	0	105	5	-	-	9.20	-	6.9	23
OTHER TRIBUTARIES																			
WILD CAT CREEK near mouth			8-29	3.9	2.4	.61	286	31	358	53	380	151	25	-	-	10.50	-	8.2	24.5
			9-6	2.6	.64	.32	225	0	810	150	50	10	20	-	-	10.85	-	8.6	25
EEL RIVER Spencer Park			9-4	11.6	10.7	.19	310	0	180	5	2680	30	30	-	-	10.49	-	8.2	24
EMBARRASS RIVER Lawrenceville			8-31	23.8	20.4	2.1	157	75	337	0	2198	450	27	-	-	8.70	-	8.1	19
"	a		9-26	5.9	5.0	.70	145	0	15	5	90	95	20	-	-	8.70	-	8.1	19
"	b		9-26	.89	.01	.82	100	0	95	0	30	180	5			8.95	-	8.2	25
MISSISINEWA RIVER mouth			9-3	.48	.08	.39	305	0	5	5	0	40	0	-	-	9.25	-	8.2	23

Station key: a - above; b - below

TABLE 15
TRADEWATER RIVER

Station	Mile	Date	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
Providence		10-4	.11	.02	.02	62	0	6	0	12	12	6	-	-	9.00		7.7	17
Sturgis		10-4	.17	.03	.07	31	6	0	0	6	37	12	-	-	5.90		7.5	18
SALINE RIVER																		
Gibsonia		10-3	1.3	.74	.02	35	20	10	0	150	85	30			5.85		7.5	19
GREEN RIVER																		
Below Dam 1	9	10-8	.02	.02	00	38	0	0	0	69	0	0	.91	0.43	8.40	13	7.7	21
Ky. Hwy. 54	25	10-8	.03	.03	00	6	0	6	0	144	0	0	-	-	7.05	-	7.7	22
Ky. Hwy. 56	45	10-7	.07	.06	00	25	0	0	0	280	6	0	-	-	6.70	-	7.8	21
Above Dam 2	64	10-7	.09	.09	00	6	0	0	0	425	0	0	-	-	6.50	-	7.6	21
Below Rough River	70	10-9	.28	.16	.10	106	0	0	0	44	18	0	-	-	7.35	-	7.6	22
Above Rough River	72	10-9	.05	.04	00	6	0	0	0	310	0	12	-	-	7.10	-	7.6	22
Dam 3	108	10-24	.04	.02	00	25	15	10	0	30	0	0	-	-	8.68	-	7.8	19.5
Dam 4	149	10-22	1.6	.00	.50	25	0	12	0	0	12	49	-	-	9.15	-	7.7	18
Mouth of Barren R.	150	10-24	.05	.01	00	10	10	10	0	10	0	10	-	-	-	-	-	19
Dam 6 below	180	10-18	.15	.14	00	645	0	5	0	10	5	5	-	1.22	9.45	-	7.8	17
Dam 6 above	182	10-18	.03	.03	00	234	0	0	0	0	0	2	.23	1.22	8.33	5	7.8	17
Munfordville	212	10-17	.02	.01	00	57	0	0	0	38	0	6	.75	0.78	9.90	8	7.7	14
Greensburg	260	10-16	.02	.02	00	18	0	0	0	62	0	0	-	-	8.31	-	7.6	15
Eunice	310	10-16	.27	.01	00	181	0	6	0	6	75	6	-	-	8.78	-	7.4	17
TRIBUTARIES																		
Nolin River	82	10-14	.19	.01	.17	6	0	0	0	44	24	0	-	-	-	-	7.9	18.5
" "	34	10-11	.51	.51	00	75	0	0	0	5	5	0	4.3	1.14	9.95	-	7.9	16
" "	83	10-14	.02	.01	00	81	0	0	0	0	6	0	-	-	8.85	10	7.9	18.5
Barren River	15	10-22	.23	.02	.05	45	3	6	0	15	6	0	.91	1.08	8.33	10	7.7	17
" "	60	10-19	.00	.00	00	10	0	0	0	20	0	0	2.3	1.81	6.78	10	7.7	16
" "	75	9-29	.04	.04	00	25	0	6	0	144	0	0	-	-	-	-	-	-
" "	90	10-19	.02	.02	00	206	6	0	0	6	-	0	2.3	0.10	8.90	-	7.7	14.5
Mud River	34	10-24	.67	.58	00	15	80	35	0	5	0	5	-	1.20	2.64	-	7.3	14
Rough River	1	10-9	.09	.01	00	69	0	6	0	50	12	25	-	-	7.20	-	7.6	21
" "	30	10-9	.06	.00	.04	50	0	0	0	0	24	0	-	-	6.10	-	7.1	17
" "	80	10-11	.31	.04	.19	301	0	12	0	6	42	6	-	-	6.15	-	7.5	16
" "	120	10-11	.03	.02	00	63	0	0	0	12	0	12	-	-	8.70	-	7.8	14
Pond River	15	10-5	.97	.10	.72	1383	0	0	0	5	130	15	-	-	8.25	8	7.2	16.5
" "	25	10-5	1.3	.14	.83	1100	5	10	0	20	234	15	-	-	5.60	8	7.0	16
" "at mouth	0	10-5	.66	.54	.09	55	0	0	0	35	15	15	-	-	-	-	7.7	23

TABLE 16

CUMBERLAND RIVER

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	D.O.	pH	Temp.
Dam F	43	11-18	.06	.04	00	16	35	5	0	20	0	6	10.97	7.7	11
Dam E	66	11-18	.10	.09	00	5	90	10	0	70	0	20	10.57	7.6	10
Dam D	88	11-15	.12	.08	00	15	90	20	0	0	0	0	10.35	7.6	11
Dam C	108	11-15	.08	.05	00	5	0	10	0	15	0	5	9.35	7.6	11
Dam B	140	11-6	1.0	.01	00	0	0	208	0	4	4	8	8.30	6.5	17
Dam A	150	11-4	4.7	.01	00	0	5	590	0	60	5	35	6.29	7.5	16.5
State Pen.	182	10-30	1.1	.07	00	5	75	265	0	20	5	5	3.21	7.3	20
Dam 1 below	187.5	11-4	.32	.14	00	0	140	50	5	5	15	5	5.99	7.3	19
Dam 1 below	187.5	10-30	.67	.06	.18		36	124	0	64	8	72	1.73	7.3	22
Dam 1 at	188	10-30	.10	.06	00	10	30	10	0	15	0	0	0.67	7.8	21
Below Nashville	189	10-30	8.2	1.1	5.0	40	210	615	0	45	65	660	2.66	7.1	18
Dam 2	201	11-1	.73	.44	00	8	44	112	0	12	28	0	6.10	7.3	18
Below Dam 3	217.5	11-7	.10	.04	00	35	30	50	0	30	0	20	9.30	7.9	16
Dam 3	218	11-1	.19	.03	00	0	24	56	0	8	0	20	9.65	7.9	18
Dam 4	237	11-7	.42	.07	00	10	70	130	5	10	5	0		7.7	16.5
Dam 5	264	11-12	.33	.06	00	25	35	15	5	90	0	0	9.70	7.8	14.5
Dam 6	281	11-13	.04	.02	00	80	35	30	0	5	5	0	10.15	7.7	13.5
Dam 8	317	11-13	.06	.02	00	205	10	10	5	0	0	0	10.05	7.8	14

TRIBUTARIES

Station	Mile	Date 1940	T	Volume I	II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	D.O.	pH	Temp.
Harpeth River	152	11-4	.07	.05	00	5	0	5	0	15	0	5	8.30	7.7	14.5
Stones River	205	10-29	.72	.10	00	88	76	60	0	8	4	8	8.05	7.7	18
Caney Fork	309	11-13	.13	.10	00	175	5	15	0	40	0	0	10.90	7.7	12

TABLE 17

OHIO RIVER

Station	Mile	Date 1940	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
Emsworth Dam	6.	10-10	0.09	0	0	75	0	0	0	5	.46	0.76	2.85	9	5.8	16.5
" "	6	10-22	0.02	10	0	45	0	0	0	0	.20	1.22	3.07	8	5.3	12.5
	13.5	10-10	0.34	5	0	45	0	60	0	0	15.	0.82	7.95	9	5.9	16.5
	13.5	10-22	0.24	10	0	40	0	120	10	5	11.	1.81	7.53	6	5.3	13.5
Montgomery Dam	31.7	10-10	.13	40	20	90	0	5	0	0	11	1.02	8.07	6	6.2	17.5
" "	31.7	10-22	.08	0	0	105	0	35	0	5	7.3	0.72	8.21	7	5.2	14.0
Dam No. 7	36.5	10-10	.16	25	0	125	0	0	5	0	11	1.23	10.10	7	6.4	17.5
" " "	36.5	10-22	.38	5	0	85	0	0	5	0	24	0.85	10.16	8	5.3	14.0
Dam No. 8	46.4	10-11	.11	20	0	70	0	0	5	0	4.6	0.65	9.59	3	6.0	17.0
" " "	46.4	10-21	.24	25	0	30	0	75	5	5	161	1.06	9.79	7	5.6	13.5
Dam No. 9	56.1	10-11	.30	0	0	205	0	5	10	0	0	0.63	9.46	3	5.9	16.0
" " "	56.1	10-21	.43	10	0	40	0	10	5	0	46	1.17	9.71	6	5.6	13.0
Dam No. 10	66	10-11	.77	0	0	160	0	15	0	10	.1	0.84	9.22	3	4.7	17.5
" " "	66	10-21	.50	265	0	68	0	40	5	0	59	1.59	9.65	8	5.4	14.5
Dam No. 11	77	10-11	.36	0	0	200	0	10	0	0	4.6	1.39	7.72	3	4.7	17.5
" " "	77	10-21	.27	155	45	40	0	0	5	0	4.3	2.25	8.39	7	5.2	13.5
Dam No. 12	87.5	10-11	.09	0	0	210	0	0	0	0	.4	1.22	6.10	4	4.7	16.5
" " "	87.5	10-21	.03	60	0	70	0	0	0	0	4.6	1.36	8.40	10	5.0	12.5
Dam No. 13	96	10-11	.07	5	0	960	0	0	0	0	2.4	1.80	8.70	4	4.7	16.5
" " "	96	10-21	.42	0	0	220	10	25	0	0	4.6	1.07	9.26	6	4.9	12.5
Dam No. 14	114	6-28	.39	30	0	130	0	135	0	0	4.6	0.90	8.43	20	7.3	22.5
" " "	114	7-10	.55	50	0	100	0	50	0	10	46	0.63	8.82	10	6.6	24.
" " "	114	7-16	.39	120	0	140	0	0	0	0	15	0.47	8.49	8	6.7	24.
" " "	114	7-30	.40	135	0	110	0	20	0	20	24	1.04	7.68	9	6.4	28.
" " "	114	8-27	1.80	0	0	1760	0	10	0	0	.4	1.19	7.89	4	4.1	24.
" " "	114	9-10	.23	0	0	250	0	5	0	5	.2	0.74	7.32	5	4.3	21.
Dam No. 15	129	6-28	.34	5	0	65	0	10	5	5	23	0.71	8.38	17	7.2	22.
" " "	129	6-30	.23	85	0	55	0	85	5	0	-	-	-	-	-	28.
" " "	129	7-10	.83	5	0	55	0	25	0	5	9.3	0.57	9.21	9	6.6	24.
" " "	129	8-15	.07	0	0	85	0	0	0	0	11	0.84	6.98	4	4.9	25.
" " "	129	8-27	00	5	0	0	0	0	0	0	.9	0.88	7.65	4	4.2	23.
" " "	129	9-10	.10	0	0	75	0	5	5	0	.4	0.40	7.89	6	4.3	22.5
Dam No. 16	146.5	6-28	.25	10	0	30	0	20	10	0	35	0.68	8.31	70	7.1	22.0
" " "	146.5	7-10	.10	35	0	200	0	65	5	0	2.3	0.70	9.29	9	6.7	23.0
" " "	146.5	7-16	.33	355	0	160	0	15	0	0	24	0.82	9.04	8	6.8	23.5
" " "	146.5	7-30	.23	30	0	105	0	28	0	0	4.3	0.82	7.73	11	6.4	28.5
" " "	146.5	8-27	.72	0	0	20	0	10	0	0	2.3	1.61	6.03	3	4.6	23.0
" " "	146.5	9-10	.20	0	0	235	0	0	0	0	.4	1.16	9.12	5	4.4	22.0

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1940	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.C.	Tby.	pH	Temp.
Dam No. 17	167.5	6-28	.32	10	0	60	0	30	0	5	240	0.90	8.31	27	7.0	22.5
" " "	167.5	7-10	1.20	100	0	100	0	95	10	0	0	1.11	9.15	11	7.0	23.0
" " "	167.5	7-16	.77	480	0	105	0	70	10	5	4.3	1.10	8.87	10	7.0	23.5
" " "	167.5	7-30	.35	230	0	290	0	20	0	5	9.3	1.32	7.87	11	6.7	29.0
" " "	167.5	8-15	.20	0	0	90		90	0	5	.9	1.45	6.85	4	6.0	27.5
" " "	167.5	8-27	1.40	5	0	10	0	15	0	10	2.3	0.72	8.63	2	4.8	24.0
" " "	167.5	9-10	.33	0	0	390	0	0	0	0	.2	0.70	9.12	7	4.9	23.0
Dam No. 18	180	6-27	1.3	50	10	150	5	160	20	25	15	1.38	8.59	70	7.1	22.0
" " "	180	7-11	1.9	125	10	230	30	70	75	5	75	1.26	9.09	16	7.0	24.5
" " "	180	7-17	4.0	480	20	225	30	395	19	20	2.3	1.32	8.62	10	7.3	24.0
" " "	180	7-29	1.7	100	0	95	10	395	20	20	23	1.77	7.36	18	7.3	29.5
" " "	180	8-14	1.2	15	0	50	0	185	0	10	9.3	1.25	7.36	3	7.4	28.0
" " "	180	8-28	.40	110	0	55	0	55	15	5	240	3.11	7.47	345	6.9	23.5
" " "	180	9-9	.89	45	0	845	15	240	5	5	24	1.25	8.39	14	6.3	23.5
Dam No. 19	192	6-27	.61	5	0	100	0	20	15	10	91	1.58	8.46	59	7.3	23.0
" " "	192	7-11	3.5	80	0	215	20	305	10	0	9.3	1.22	8.89	14	6.9	23.0
" " "	192	7-17	2.3	375	0	70	0	60	0	20	24	5.43	8.43	8	7.5	24.0
" " "	192	7-29	1.2	80	0	65	0	255	5	20	93	1.57	7.61	40	7.3	30.0
" " "	192	8-14	.86	25	20	65	0	360	10	15	46	1.26	7.11	5	7.5	28.5
" " "	192	8-26	.97	10	0	25	0	75	0	5	21	1.13	7.52	4	7.1	23.5
" " "	192	9-9	.67	30	0	590	35	295	5	10	93	1.50	8.10	14	6.8	23.5
Dam No. 20	202.5	6-27	1.6	16	0	204	24	112	24	8	43	1.36	8.30	48	7.3	23.0
" " "	202.5	7-11	3.7	105	0	305	0	280	10	0	121	1.05	8.92	16	6.9	24.0
" " "	202.5	7-17	2.9	252	15	60	5	170	15	15	110	1.41	8.56	12	7.2	23.5
" " "	202.5	7-29	.60	25	10	115	5	375	0	10	93	1.77	7.51	49	7.2	29.0
" " "	202.5	8-26	.67	0	0	45	0	185	0	0	2.3	1.05	7.72	4	7.1	24.0
" " "	202.5	9-9	.16	15	0	25	0	185	0	0	11	1.78	8.60	12	6.8	23.5
Dam No. 21	214.5	6-27	.78	15	5	190	0	60	15	0	75	1.51	8.33	48	7.2	22.
" " "	214.5	7-11	1.0	50	0	135	0	185	0	0	46	1.15	9.02	17	6.9	24.
" " "	214.5	7-17	2.6	630	5	35	5	277	15	0	15	1.25	8.43	12	7.2	23.
" " "	214.5	8-14	1.5	5	0	185	0	255	0	5	.9	1.15	7.75	4	7.4	27.5
" " "	214.5	8-26	.83	10	0	15	0	250	0	0	15	1.31	8.03	3	7.1	25.
" " "	214.5	9-9	.24	5	0	35	0	160	10	0	24	1.10	8.73	12	6.8	23.
Dam No. 22	221	6-27	.48	10	16	239	0	26	5	0	110	1.45	8.12	84	7.2	23.
" " "	221	7-11	2.40	10	0	10	10	115	0	0	15	1.21	8.79	15	6.7	23.
" " "	221	7-17	1.00	615	4	28	0	128	9	4	15	0.96	8.40	13	7.0	21.5
" " "	221	7-29	.33	65	0	40	0	100	0	5	15	1.22	7.12	77	7.1	27.
" " "	221	8-14	1.3	0	0	165	5	335	0	0	.7	1.18	7.82	5	7.4	27.
" " "	221	8-26	.81	20	0	110	0	205	5	0	24	1.11	7.89	3	7.1	23.
" " "	221	9-9	.55	35	0	200	15	445	0	5	2.3	1.00	8.62	13	6.8	22.
Dam No. 23	231.5	6-27	1.2	5	5	145	0	35	20	0	230	1.45	8.26	62	7.2	23.
" " "	231.5	7-11	.06	0	0	5	0	60	0	0	3.9	0.85	8.91	16	6.6	24.
" " "	231.5	7-17	1.10	765	0	50	10	115	15	10	9.3	1.37	8.57	12	7.1	23.5
" " "	231.5	7-29	.56	35	5	50	5	255	5	10	4.3	1.23	7.34	41	7.1	29.
" " "	231.5	8-26	1.40	0	5	115	0	475	0	0	1.5	1.28	8.06	3	7.0	24.5
" " "	231.5	9-9	.72	30	0	125	5	575	5	0	2.3	1.51	9.27	11	6.8	22.5

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1939	Volume	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
	316	6-23	2.9	16	0	124	16	3,544	8	16	93	1.32	8.63	65	-	26
		6-29	.19	4	0	16	4	130	0	4	43	1.60	7.32	85.	7.3	26
		7-7	.49	4	0	28	0	188	20	4	30	1.93	7.99	-	-	26
		7-13	.59	4	16	96	0	40	0	8	91	0.48	7.70	-	-	26.5
		7-21	.21	0	16	48	0	64	4	0	333	0.95	7.89	-	-	25
		7-27	.42	36	104	64	36	52	8	4	72	0.84	8.27	-	-	26
		8-4	.29	16	0	80	0	72	0	0	59	1.09	7.60	-	-	26
		8-10	.12	304	28	52	20	64	0	16	95	0.76	8.07	-	-	25.5
		8-18	4.9	52	24	66	0	1,684	0	20	515	0.61	7.55	-	-	27.5
		8-24	.37	112	20	36	40	164	4	16	159	0.88	7.90	-	-	26.5
		9-1	.09	8	36	16	20	12	0	16	310	0.90	7.23	6	7.3	26
		9-6	.25	52	48	12	0	4	0	20	264	0.92	7.27	-	-	25
		9-14	.02	4	12	8	0	4	0	0	69	0.70	7.55	-	-	26.5
		9-20	.08	16	20	8	0	0	0	8	142	0.85	7.39	-	-	24
		9-28	.08	16	4	8	0	4	4	4	76	0.92	7.59	-	-	23.5
		10-12	.43	24	4	140	4	168	0	0	387	0.67	8.32	-	-	20
		10-24	.26	0	4	56	0	8	0	0	283	0.61	9.31	-	-	16.5
		11-9	.30	12	24	108	88	140	0	0	121	1.07	11.34	-	-	11
		11-27	.11	36	0	60	12	44	0	0	93	0.81	12.28	-	-	8
		12-15	.05	56	0	24	8	48	0	8	18	0.93	12.29	-	-	6
		12-28	.02	4	0	8	0	32	0	0	33	1.05	12.72	-	-	3.5
Dam 29	320	6-23	2.0	3	0	75	5	1,506	3	9	116	1.41	8.26	95	-	26
		6-29	1.5	27	3	45	0	84	3	3	93	1.57	7.43	90	7.2	26
		7-13	.42	16	4	80	0	20	4	8	240	0.64	7.66	100	7.5	26.5
		7-21	.35	12	8	12	0	16	12	16	523	1.02	7.80	200	7.3	25
		7-27	.60	0	272	76	12	68	12	16	119	1.11	8.23	24	7.2	26.5
		8-10	.47	12	36	100	40	56	4	16	399	.97	8.13	23	7.4	26
		8-18	.67	16	32	84	4	100	8	0	312	0.63	7.62	45	7.6	27.5
		8-22	13.3	52	36	72	8	4,400	4	20	471	1.11	7.54	29	7.4	26
		9-6	.41	92	120	28	4	12	4	45	264	1.14	7.12	9	7.3	25.5
		9-12	.26	32	72	36	32	20	0	24	129	0.86	7.57	2	7.7	25
		9-14	.05	56	16	8	0	8	4	0	82	0.98	7.37	6	7.6	26.5
		9-20	.02	4	0	8	0	36	0	0	81	0.68	7.60	4	7.4	23.5
		9-28	.39	20	108	64	0	12	8	4	76	1.07	7.90	3	7.7	24.0
		10-12	.19	4	0	120	40	56	0	4	125	0.77	8.30	4	7.6	21.0
		11-27	.21	65	4	44	12	36	0	8	48	0.97	12.17	7	7.4	7.5
	330	6-14	.63	99	30	156	0	125	4	30	181	2.42	8.5	23	-	25
		6-20	3.2	60	4	40	0	580	4	0	102	1.16	7.73	27	-	25.5
		6-30	.11	4	0	52	0	28	4	8	240	1.76	6.57	75	7.2	26.5
		7-14	.12	0	0	40	8	8	4	0	69	1.07	7.85	-	-	25.5
		7-20	.51	16	28	28	0	8	0	16	252	1.10	8.08	-	-	26
		7-28	.35	20	28	104	4	32	8	12	387	1.42	7.98	-	-	26
		8-3	1.1	28	0	32	8	64	0	4	150	1.24	7.5	-	-	26
		8-11	.44	240	108	120	40	108	4	4	165	0.88	8.31	-	-	25.5
		8-17	3.8	16	8	32	12	1216	16	0	115	0.54	7.62	-	-	27.5
		8-29	.47	32	44	8	28	164	0	0	76	0.85	7.44	-	-	26
		8-31	.06	8	40	20	0	8	0	4	199	0.81	7.34	-	-	25.5
		9-7	.41	44	96	12	16	0	0	36	106	0.80	7.44	-	-	25.5
		9-15	1.5	12	24	52	8	32	0	0	391	0.73	7.14	-	-	26
		9-21	.06	0	16	0	4	12	0	0	338	0.66	7.30	-	--	23
		9-29	.04	8	36	0	0	8	0	0	337	0.81	7.56	-	-	23.5
		10-13	.08	44	16	48	0	4	0	4	167	0.53	8.46	-	-	20
		10-23	.26	0	8	44	0	24	4	0	177	0.64	9.18	-	-	16
		11-10	.34	8	28	32	4	104	8	4	67	0.91	11.34	-	-	10.5

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1939	Volume	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
Dam 29, cont.	337	6-14	1.5	184	44	452	0	320	4	8	93	1.96	7.89	20	-	25
		6-20	.60	66	0	48	0	559	3	0	138	1.36	7.58	32	-	26
		6-30	.09	45	0	41	0	48	0	0	195	1.63	6.80	75	7.2	25.5
		7-14	.71	16	28	152	0	12	8	8	95	1.17	7.55	85	7.5	26.5
		7-20	.40	36	80	52	4	4	0	24	65	1.15	7.68	39	7.2	25.5
		7-28	.76	56	144	108	20	82	4	16	74	1.41	7.96	22	7.3	26.5
		8-3	1.3	36	0	56	8	104	16	12	161	1.29	6.87	85	7.1	26
		8-11	.42	146	260	98	64	56	20	40	157	1.10	7.93	13	7.4	25.5
		8-17	4.5	40	36	84	8	1436	8	8	73	0.86	7.29	45	7.3	27
		8-29	.33	72	36	68	40	76	0	8	27	0.95	7.29	4	7.2	26
		8-31	.10	8	52	28	4	88	0	8	60	0.89	7.02	5	7.2	25.5
		9-15	.06	30	8	16	4	24	0	0	50	0.76	7.30	5	7.5	26
		9-21	.85	0	30	36	0	12	4	8	31	1.01	7.20	7	7.2	23
		9-29	.05	16	4	28	0	68	0	0	52	0.67	7.55	3	7.8	23
		10-13	.03	12	28	0	0	0	0	0	38	1.01	8.51	5	8.0	20
		10-23	.05	0	12	0	8	0	8	16	89	0.97	9.14	4	7.7	16.5
		11-10	.28	36	88	4	0	168	4	0	76	0.72	11.04	7	7.3	10
		11-24	.08	68	28	104	0	24	0	0	31	0.91	11.68	4	7.5	8.5
Dam 33	405	5-1	.32	8	40	32	0	12	0	4	43	1.49	9.80	47	7.5	13
		5-9	37.1	40	184	80	0	5408	4	52	4.3	1.14	9.89	15	7.7	17.5
		7-18	.94	4	0	16	0	4	12	12	9.3	1.99	7.93	53	7.3	25.5
		7-24	.34	4	0	76	0	4	4	8	110	2.41	7.15	170	7.3	26
		8-1	.50	28	0	40	0	140	12	4	75	1.92	7.06	78	7.2	26.5
		8-7	.37	20	16	16	4	284	4	20	9.1	1.33	7.76	27	7.5	27
		8-15	.53	236	0	0	0	80	0	12	24	2.64	7.20	65	7.3	27.5
		8-21	4.8	4	0	12	4	1470	0	4	23	2.14	7.83	46	7.3	27
		8-29	.46	52	0	56	12	228	0	4	4.6	.90	7.60	15	7.9	26
		9-12	.25	0	4	44	40	56	4	0	.23	1.21	7.76	8	7.6	25.5
		10-30	.36	28	8	44	8	296	0	4	43	1.42	8.65	38	7.3	15.5
		11-13	.56	60	56	108	0	304	4	0	2.3	1.39	11.12	7	7.2	9
		11-27	1.2	216	68	270	0	116	4	28	15	1.36	11.70	10	7.3	7.5
Dam 34	434	5-1	.40	8	44	12	0	16	0	12	23	2.92	9.36	51	7.5	13.5
		5-9	26.6	28	164	64	0	2692	0	8	9.3	1.26	10.13	20	7.8	17
		5-17	11.9	50	144	64	0	2032	20	24	4.3	1.26	9.94	8	7.7	18
		5-25	3.0	180	16	68	0	948	0	72	2	2.32	9.13	4	7.6	23
		6-12	.51	20	0	68	0	326	0	4	22	1.22	7.70	13	7.8	24.5
		6-20	.11	81	3	37	5	45	6	0	109	2.17	7.34	108	7.6	26
		6-26	.89	17	3	102	0	987	6	17	36	3.58	8.10	97	7.6	25
		7-18	.82	0	0	63	0	41	27	12	53	1.15	7.81	48	7.4	25
		7-24	.45	0	0	4	8	12	4	12	31	1.65	7.10	190	7.3	25.5
		8-1	.43	35	4	80	4	32	16	4	30	1.37	6.66	125	7.3	25.5
		8-7	.45	12	0	100	12	188	12	0	20	1.23	7.41	23	7.4	26.5
		8-21	1.0	20	0	48	4	456	8	20	264	1.56	7.06	122	7.3	26.5
		8-29	.46	24	0	12	0	356	12	0	1	1.60	8.07	15	7.7	25
		9-12	.08	4	0	44	8	48	0	4	1	0.92	7.90	8	7.6	24.5
		9-18	00	0	0	0	0	0	0	0	1	0.86	7.99	7	-	24.5
		10-2	.05	0	0	20	0	12	0	0	7	0.91	8.38	13	7.5	20
		10-10	.09	8	4	36	0	44	4	0	1	1.05	8.54	11	7.7	21
		10-30	.49	8	0	36	12	196	0	0	9	1.44	8.82	64	7.5	14
		11-13	.62	204	4	128	0	136	4	12	3	.85	11.28	7	7.2	6
		11-27	1.3	326	56	308	8	160	0	4	8	1.08	11.58	12	7.5	9

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1939	Volume total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
Dam 36	461	5-1	.24	16	16	4	0	24	0	4	3.6	1.18	9.43	56	7.7	12
		5-9	32.8	152	172	92	0	2,780	8	8	2.3	1.22	10.27	25	7.8	15
		5-17	.18.3	12	44	76	0	4,768	0	92	0.3	1.70	10.00	5	7.8	17
		5-23	38.6	100	52	64	0	3,104	0	92	1	0.88	9,48	6	7.4	21
		6-8	3.8	244	0	184	0	2,452	28	16	4.3	1.84	7.81	29	8.0	24
		6-20	.88	96	0	36	4	180	0	0	150	2.44	7.43	230	7.7	24
		7-18	1.5	12	0	132	0	52	36	8	9.3	1.33	8.03	60	7.3	24
		7-28	.30	4	0	16	0	52	16	8	23	2.15	7.69	64	7.3	25
		8-3	.62	36	16	12	0	88	8	4	30	1.35	6.63	90	7.2	25.5
		8-7	.49	4	0	24	4	24	8	4	43	1.08	7.37	23	7.4	26
		8-21	1.1	40	0	40	4	152	8	36	43	4.95	7.16	39	7.3	25.5
		8-29	.92	16	0	44	0	768	8	4	0.93	1.00	8.65	15	8.0	24
		9-8	.17	4	0	4	4	168	4	0	2.4	1.60	7.68	10	7.5	26
		9-12	.08	4	0	0	28	52	0	0	0.43	1.01	7.84	8	7.6	24.5
		9-18	1.5	0	0	526	0	24	0	0	0.93	0.66	8.68	7	-	24.5
		10-2	.11	0	0	64	4	45	0	0	4.3	0.83	8.30	14	7.5	17.5
		10-12	00	12	0	0	0	0	0	0	0.93	0.55	8.44	6	7.5	18.5
		10-30	.43	148	4	64	8	132	0	0	3.6	1.15	9.48	60	7.5	14.0
		11-13	1.3	424	116	98	4	232	16	24	0.93	1.30	11.68	8	7.3	9
		11-27	2.0	260	4	156	4	140	12	4	3	1.46	12.10	14	7.5	8
Dam 37	483	5-4	1.1	16	88	32	0	112	4	28	240	1.49	8.92	36	7.5	14
		5-12	74.7	8	148	105	0	3,164	16	52	2,400	2.51	9.58	12	7.8	19
		5-18	7.6	4	27	54	0	1,572	12	3	2,150	2.99	8.97	8	7.9	20
		5-22	27.8	156	100	56	0	2,552	8	64	230	4.93	7.35	33	7.6	24
		6-1	3.5	308	0	52	0	1,468	12	4	2,300	4.03	6,93	10	7.6	25
		6-13	.28	24	16	39	6	260	0	3	430	3.46	7.28	132	7.8	23
		6-19	.42	16	0	48	0	240	4	8	300	3.30	6.77	205	9.0	26
		7-17	.60	4	0	42	3	30	36	6	390	2.10	7.40	105	7.2	26
		7-31	.77	9	18	73	24	45	18	15	400	3.15	6.65	160	7.4	27
		8-8	.39	12	0	51	4	132	11	0	24,000	2.64	5.59	50	7.3	27
		8-13	2.3	24	24	76	8	120	36	8	93	1.07	3.70	10	7.3	26
		8-21	.84	20	4	44	20	284	8	32	2,400	2.30	3.03	15	7.2	23
		8-28	1.2	108	0	56	8	994	12	72	313	1.79	6.27	25	7.5	26
		9-5	1.7	12	0	27	0	2,044	8	0	91	3.06	5.19	15	7.8	25
		9-11	.23	12	0	48	0	88	0	0	373	1.11	2.96	10	7.6	26
		9-19	.55	12	0	356	4	136	0	4	240	1.65	5.58	10	7.4	25
		9-25	1.5	16	20	644	8	72	0	118	2,400	2.56	2.22	15	7.3	24
		10-9	.37	0	0	184	4	64	0	4	13,100	1.88	4.68	7	7.5	22
		10-27	.33	64	0	24	0	488	0	0	46,000	1.05	6.54	10	7.5	18
		10-31	.74	128	4	136	8	336	8	4	910	1.85	8.84	45	7.4	13
		11-14	.49	180	0	92	0	272	4	16	230	1.32	11.33	-	7.5	9
		11-30	.20	404	4	120	68	160	0	0	2,340	3.44	11.08	-	-	6

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1939	Volume total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.C.	Tby.	pH	Temp.
Dam 38	503	5-4	2.0	12	56	72	0	55	4	12	1,533	1.88	8.68	45	7.5	14
		5-12	39.8	3	0	108	0	3,768	0	33	1,665	2.59	9.50	15	7.9	17
		5-18	16.6	4	52	40	0	3,456	16	20	1,100	2.71	9.17	8	7.9	20
		5-22	24.1	116	88	44	0	2,372	4	32	430	2.55	8.67	25	7.8	21.5
		6-1	12.4	244	0	168	0	1,198	8	44	230	2.65	7.77	10	7.7	25
		6-5	6.0	232	44	112	0	4,432	12	28	443	2.90	7.25	105	7.8	24
		6-13	1.4	48	0	268	8	380	4	24	1,100	1.98	6.65	95	8.0	23
		6-19	5.1	16	8	20	0	56	0	4	390	2.57	6.08	90	9.0	25
		7-17	2.3	16	30	325	0	212	68	28	930	2.46	7.0	84	7.2	25
		7-31	.87	6	3	87	3	158	9	12	930	3.20	5.80	265	7.5	26
		8-8	.60	40	4	116	8	162	0	0	430	1.72	6.63	70	7.2	26
		8-14	2.3	12	4	136	8	200	36	20	430	2.71	6.08	47	7.7	27
		8-22	1.2	0	8	56	12	680	16	56	230	1.83	6.33	46	7.5	26
		8-28	1.8	20	8	112	12	1,828	56	28	150	2.20	8.20	18	7.6	24.5
		9-5	1.7	24	0	104	12	2,556	4	4	36	2.58	6.46	15	7.8	24
		9-19	1.2	0	0	172	24	196	8	0	9.3	1.81	4.70	10	7.5	23
		9-25	1.8	24	8	1,352	8	80	0	32	240	2.28	6.93	15	7.6	22
		10-9	.53	16	12	185	16	340	4	32	240	2.05	5.53	8	7.5	21
		10-27	.39	84	0	44	32	348	8	4	1,500	3.02	7.10	7	7.5	17
		10-31	1.1	440	8	252	0	266	0	8	430	1.93	8.79	43	7.5	12
		11-14	.48	276	8	56	0	172	16	20	2,400	2.48	11.13	12	7.3	8
		11-30	2.1	384	12	296	168	136	4	52	2,010	3.37	10.37	0	-	7
Dam 39	531	5-4	1.7	8	104	120	0	160	4	20	240	1.86	8.67	50	7.4	14
		5-12	45.1	56	160	132	0	2,988	16	88	430	2.64	9.53	15	7.9	17.5
		5-16	49.7	20	164	168	0	6,340	8	96	32	2.65	10.35	8	8.1	18
		5-26	26.0	196	0	192	0	3,744	4	60	230	2.44	8.17	5	7.7	24
		6-9	5.7	216	0	212	0	4,596	5	24	144	2.34	7.42	144	8.2	27
		6-15	.48	28	0	32	0	236	4	8	60	2.03	6.05	62	7.8	23
		6-23	.46	72	20	40	0	116	20	8	503	2.86	5.71	215	7.7	26
		7-21	.61	0	8	88	0	136	20	4	137	1.98	6.32	112	7.3	26
		7-27	.73	8	8	84	0	476	8	16	43	1.90	6.82	112	7.3	26
		8-4	.90	28	40	92	56	92	16	4	703	1.15	5.34	89	7.5	26.5
		8-10	1.4	64	12	128	36	584	24	4	36	1.10	6.63	22	7.3	26.5
		8-18	.34	12	24	80	64	44	12	4	23	1.54	5.58	140	7.3	27.5
		8-24	1.1	24	4	70	12	1,324	12		43	1.59	7.20	37	7.8	26.5
		9-1	2.7	4	4	120	4	2,836	0	0	2	4.21	11.53	15	7.7	25.5
		9-7	.52	12	4	120	0	288	0	44	3	2.07	7.87	15	7.9	25.5
		9-15	.71	20	8	128	44	1,732	4	4	1	1.57	6.70	8	7.6	26
		9-21	1.2	12	12	236	12	284	4	0	1	1.57	6.50	15	7.5	24.5
		9-29	3.2	20	60	1,708	16	2,668	0	0	3.6	2.53	10.20	14	8.1	23
		10-13	1.6	76	28	280	112	2,152	0	12	7	2.10	8.55	4	7.5	19
		10-19	.75	0	0	288	20	0	0	12	16	1.76	8.99	5	7.6	16.5
		10-27	1.8	124	24	352	20	92	8	4	24	1.61	8.17	5	7.6	17.5
		11-2	6.0	36	16	56	0	108	0	28	34	2.42	8.71	1960	7.3	13
		11-16	.94	1,412	48	168	4	448	12	8	10	2.20	11.40	144	7.3	9
		11-30	2.0	320	16	116	0	20	4	48	338	1.85	10.93	-	-	7.5

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1940	Volume total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
	547.8	10-15	1.4	15	25	110	0	1,250	5	5	24	3.29	11.58	30	8.4	18.5
	559.5	7-29	.63	5	5	115	10	533	5	0	89	3.26	8.57	13	7.6	30.0
	561	10-16	1.40	30	50	80	0	1,175	0	35	23	3.31	10.90	25	8.4	17.5
	562.6	7-29	.57	0	0	105	0	1,530	0	0	419	1.64	7.64	15	7.6	30.0
	562.6	10-16	.66	0	10	100	10	759	5	30	9.3	2.71	11.40	11	8.5	18.0
	576.1	7-29	.80	15	15	105	5	2,165	5	0	142	2.12	7.40	15	7.4	29.5
	576.1	10-16	1.70	24	12	281		2,215	0	36	4.3	3.02	10.35	11	8.1	17.5
	600	8-9	1.1	6	0	148	0	1,074	0	0	.91	2.20	8.46	8	8.1	28.5
	608.5	8-12	1.4	0	6	58	0	907	0	6	230	2.39	8.25	12	8.0	28.0
	608.5	10-25	.16	0	6	110	0	285	0	0	460	2.52	7.52	5	7.7	16.0
	610	8-12	1.2	0	0	105	0	1,035	5	0	930	2.26	8.54	11	8.0	29.0
	610	10-25	.55	0	0	45	0	330	0	0	1,100	2.43	7.40	8	7.5	17.0
	614	8-12	3.1	12	0	142	25	3,664	0	0	91	2.74	8.35	8	8.1	28.5
	614	10-25	.32	0	5	65	6	285	0	5	1,100	2.40	7.21	10	7.5	17.5
	628	10-23	.21	0	0	120	0	185	0	0	1,100	2.20	7.51	8	7.5	16.0
Dam No. 43	633	10-23	.21	5	0	30	0	110	0	0	43	2.10	7.80	5	7.6	16.5
	637.1	10-23	.57	0	25	60	0	610	0	5	60	-	-	-	7.6	16.5
	662.9	8-19	3.9	5	0	135	5	3,610	5	0	110	3.48	6.86	60	7.7	28.0
	665	8-19	3.2	5	0	170	0	4,240	0	0	150	3.47	6.50	62	7.8	28.0
Dam No. 45	703	8-19	1.6	5	0	65	0	3,115	0	5	75	2.51	5.93	50	7.7	26.0
	711.3	8-21	.27	5	0	15	0	145	0	0	110	2.16	6.35	41	7.5	27.0
	722.7	8-21	3.60	5	0	65	0	2,895	5	10	46	2.09	6.30	38	7.5	27.0
	730.6	8-21	5.10	5	5	155	30	6,300	0	5	46	2.40	6.29	50	7.5	26.5
Dam No. 46	756.5	9-4	.09	0	0	135	0	350	0	0	24	1.78	6.74	60	7.5	24.0
	756.5	10-30	1.1	5	0	525	10	70	0	0	3.6	2.55	9.33	10	8.1	17.5
	760	9-4	.86	20	0	165	5	5	0	5	110	3.60	7.18	60	7.5	23.5
	760	10-30	1.8	0	0	1,225	0	170	0	30	43	2.35	9.40	8	8.0	16.5
Dam No. 48	777.7	9-4	1.2	0	0	80	0	550	0	5	24	1.38	7.33	60	7.5	24.0
	777.7	10-30	.56	0	0	1,565	0	75	0	5	23	1.77	8.57	10	7.9	16.5

TABLE 17, cont.
OHIO RIVER

Station	Mile	Date 1940	Volume	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	BOD.	D.O.	Tby.	pH	Temp.
	791	9-4	.52	0	0	165	0	1,285	0	15	46	2.20	7.31	50	7.6	23.5
	791	11-1	.49	0	0	35	0	220	0	0	43	1.99	9.17	12	7.9	17.5
	797.7	10-29	1.1	0	0	225	0	220	0	5	240	2.76	9.04	13	8.3	18.0
	803	9-3	2.8	0	0	1,650	0	1,165	10	0	75	1.45	7.21	63	7.6	25.5
	803	10-29	.69	0	0	50	10	215	0	5	43	2.43	9.73	13	8.4	16.5
	809	9-3	2.7	30	0	3,050	0	1,270	10	15	150	1.60	7.14	65	7.6	25.5
	809	10-29	.98	0	0	925	5	340	0	0	23	2.78	9.97	13	8.5	18.6
	829.1	9-11	2.0	15	0	255	5	285	5	10	24	1.99	8.54	22	7.7	22.3
	829.1	11-6	6.8	15	0	390	20	2,200	0	60	43	2.18	9.68	13	7.7	14.5
Dam No. 49	845	9-11	1.3	5	0	240	0	525	15	15	24	1.80	8.36	18	7.7	23.5
	845	11-6	8.0	0	10	210	0	2,295	10	35	46	2.00	9.62	13	7.7	15.0
	852.3	9-11	.98	20	0	1,010	40	540	0	15	15	1.91	9.38	18	7.9	24.0
	852.3	11-6	4.3	0	35	165	0	1,300	0	35	24	2.63	9.87	15	7.5	14.0
	864.8	9-10	1.6	15	0	305	115	600	15	25	9.3	2.98	8.49	18	7.9	24.5
	864.8	11-5	2.5	15	10	490	5	265	0	35	24	1.97	9.50	15	7.8	15.5
	870.7	9-10	.30	10	5	639	136	352	0	5	9.3	1.43	8.46	15	7.9	25.0
	870.7	11-5	1.7	15	0	760	5	4,025	0	15	7.5	1.90	9.40	18	7.8	16.0
Dam No. 50	876.8	9-10	.26	0	0	300	35	365	10	0	2.3	1.49	8.63	18	8.0	24.5
	876.8	11-5	2.0	10	5	1,290	0	1,400	0	30	9.3	1.74	9.52	15	7.8	17.0
	891.6	9-20	.91	0	0	1,870	60	150	0	0	.73	2.00	9.44	13	8.4	22.5
	927.3	9-20	.96	0	0	1,110	125	105	0	10	2.3	1.65	9.59	12	8.3	24.0
	934.3	9-23	.04	0	0	80	30	5	0	0	2	1.84	8.99	15	7.9	25.0
	934.3	11-22	1.40	15	15	85	0	965	0	10	2.3	8.34	10.40	18	7.7	12.0
Dam No. 52	938.9	9-23	.09	5	0	75	60	25	0	0	7.5	1.00	8.70	12	7.9	25.0
	938.9	11-22	3.8	30	20	105	0	1,370	0	5	.91	1.86	11.57	18	7.8	11.0
	962.6	9-23	.24	0	0	205	30	25	0	0	-	-	-	-	-	26.0
	962.6	11-22	2.0	15	10	100	0	2,424	0	0	9.3	2.31	12.78	20	7.9	10.5
	978	10-3	.62	5	0	225	50	540	0	10	2.3	1.50	9.39	10	8.0	20
	978	11-25	4.2	10	25	170	0	1,845	0	0	2.1	2.45	11.80	125	7.6	9.5
	981	10-3	.34	5	0	60	20	385	0	0	24.0	1.59	9.31	130	7.9	19.5

A P P E N D I X   I

SCIOTO RIVER BIOLOGICAL STUDIES

SCIOTO RIVER BIOLOGICAL STUDIES

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SCIOTO RIVER BIOLOGICAL STUDIES

Introduction

The lower half of the Scioto River was the object of an intensive study during thirty months from February, 1938, to July, 1939. During that time, the plankton was studied both in the field and in the U. S. Public Health Service laboratory at Cincinnati at weekly intervals, and the life of the bottom sediments at less frequent intervals. Reference may be had to Volume III of the Final Report of the Ohio River Pollution Survey[1] for the hydrography of the stream, population figures, and extent and sources of pollution, also to the Drainage Basin Committee's reports,[2] while Public Health Bulletin 276[3] gives the detailed hydrobiological findings of the Scioto River studies.

Headwater Streams

The headwaters of the Scioto and Olentangy Rivers, above Columbus, and the headwaters of the five creek basins - Paint, Deer, Darby, Big Walnut and Little Walnut - are located in areas where population is dense, where industry is concentrated, and where agricultural productivity is high. Almost all of the headwater streams, therefore, receive heavy loads of human, some industrial pollution, and extensive agricultural drainage, and they are consequently well fertilized. Furthermore, the gradients of these streams are slight and, in their lazy flow, time is allowed for aging of the water. Because of these two factors, biological productivity should be high.

No reliable index of biological productivity for long periods of time is available for the headwaters, but for some stations series of samples covering a few weeks have been examined. For many other points two samples, one above and one below a town or source of possible pollution, have been examined. The general idea gained from these scattered observations is that biological productivity, as far as plankton is concerned, is high in the headwater streams. For example, one of the samples from the Scioto in the vicinity of Kenton, very close to its source, contained 35 species of plankton organisms, some of them in large numbers (October 2, 1939).

In the small headwater streams, radical differences in the plankton above and below a town are sometimes apparent and may be correlated with chemical and bacterial findings indicative of gross pollution below the town. Paint Creek, above and below Washington Court House, and above and below Greenfield, offers excellent examples. In December, 1939, and on into March, 1940, the creek above both towns showed large numbers of Chrysophyceae and Cryptophyceae, with abundant D.O., low B.O.D. values, and low coliform counts. Below the towns these conditions were reversed; at times there was no oxygen in some parts of the creek below Washington Court House. At other times or in other stretches of the creek, there were D.O. values of 10.6 p.p.m., along with 10.9 p.p.m. B.O.D. and a coliform count per ml. of 1000 (most probable number). Cryptophyceae and Chrysophyceae were generally less in numbers below the towns. The flora and fauna were abundant, but principally made up of forms characteristic of activated sludge or a trickling filter - Sphaerotilus, Beggiatoa, Chromatium and not infrequently large numbers of ciliate protozoa. A few species of Euglena were usually present, even if lacking above the towns, but only one species, Euglena viridis, was ever abundant; at one time it was so abundant below Washington Court House (however, in a recovery zone) as to constitute a bloom in late December and early January. There was sufficient green plankton in some of the samples to have been a factor in accouting for the high D.O. values.

Above Columbus Sewage Plant Outfall

Columbus uses much of the river water at times of low flow, but there was always a fair population of plankton organisms at the lower margin of the city, to provide abundant reseeding of the water returned to the river via the sewers and sewage disposal plant. A sampling point located at the lower margin of the city was the uppermost station for routine sampling in the detailed study of the river. It was just below a low head dam and its plankton population generally consisted of organisms that lived principally by photosynthesis and were not dependent on organic matter. That is, clean water organisms were generally predominant at this station.

The Scioto River, from the lower margin of the city to the sewage treatment plant outfall, was frequently sluggish in flow and, besides receiving storm water drainage from the city, also received some raw sewage. It rapidly deteriorated in

sanitary quality, and on at least two occasions appeared to be septic about a mile below the uppermost regular sampling point. In effect, the storm drainage and some raw sewage created a zone through which many organisms could not pass, because of oxygen deficiency, H_2S poisoning, and possibly other causes. Only a few species showed a rise between Columbus and Shadeville, the second sampling station, but it was not at all unusual to find empty shells, or dead individuals, of clean water types, at Shadeville or in the intervening stretch, and the work sheets for the survey sometimes have notations to that effect.

Objectives

The plankton work of the Scioto River Survey had several objectives. One was to show what organisms were to be found in the stream, over a long period of time. It was hoped that this would provide a fairly comprehensive list of river plankton species. Most plankton forms are cosmopolitan, and it was not anticipated that extremes of environment, other than the initial badly polluted stretch, would be encountered, so a normal river plankton was envisaged.

A second objective was to determine what, if any effect, Columbus sewage exerted on the plankton, especially with regard to the successive modes of treatment - trickling filter, primary sedimentation and complete treatment.

A third objective was to seek correlations between physicochemical conditions, coliform counts, and the qualitative and quantitative plankton findings. This last would involve an evaluation of "indicator species," as well as determining the causative factors for peaks in the plankton population.

Results

It is not too much to say that all these aims were achieved, and in addition certain refinements in the tachnique of handling plankton were evolved, while, as a side issue, a number of new species of algae and Protozoa were described.

<u>Species Found</u> - The Scioto yielded 448 groups, genera or species of plankton organisms during the survey. One whole class of algae, the dinoflagellates or Dinophyceae, was very poorly classified as to genera and species. They were few in

number in the Scioto, as in streams generally, but are often abundant in lakes and reservoirs. A number of genera, e.g., Chlamydomonas, were not classified to species. Conversely, because of the technique followed, it was possible to identify and count a great many very small organisms, not heretofore usually considered in such surveys. Certainly 448 species or groups of organisms have not heretofore been described from any stream. Subsequent work, including very detailed studies of Tanner's, Laughery, Hogan and Four Mile Creeks; the Cumberland, Duck, Licking, Little Miami and Miami Rivers, all within the Ohio Basin, have confirmed the basic nature of the plankton list. This has also been shown to be substantially correct by less detailed studies of many Ohio Basin streams as well as some studies of Atlantic and Gulf Coastal streams, and the Columbia River of the Pacific Coast. New species are found elsewhere from time to time, but thus far the great majority of forms found elsewhere has corresponded closely with those found in the Scioto. This even holds true for relative numbers - a species common in the Scioto tends to be common elsewhere, even if the abundance in the Scioto and the second source is in a ratio of 10 to 1 or higher.

Columbus Sewage Effects - With regard to the second objective, there was ample evidence as to the effect of the Columbus sewage. There was a large number of species which occurred with some frequency at the lower margin of the city. Some clean water types occurred here in abundance, but more commonly, numbers of all organisms were low at this station, and they decreased still more, until at Shadeville the low population point for most of the enumerated organisms was reached. The few exceptions were sewage-tolerant forms typified by Sphaerotilus. It is to be noted also that some forms appeared at Shadeville which were not found above Shadeville; these too were usually sewage-tolerant forms, as certain ciliate protozoa.

A short distance below Shadeville, an increase in the protistan population of the stream began, and this increase reached very high numbers. This was evidence of the fertilizing power of the sewage plant effluent. The types of organisms were those usually found in recovery or clean water zones; for example, Big Walnut Creek often poured large numbers of Chrysophyceae into the river, and these did not die off, as they did in the stretch between the city margin and Shadeville. Evidently the effluent from the sewage treatment plant provided better water than that below the city but above the treatment plant outfall. At Shadeville there were perhaps more organisms typical of carbonaceous oxidation than at any of the other stations, but they soon disappeared and those typical of nitrogenous oxidation,

or those dependent on photosynthesis quickly became the bulk of the population. From a biological standpoint, the plant effluent greatly enriched the river, but with material already far along towards stabilization.

In one respect the findings were disappointing. There was no marked difference in the stream flora and fauna traceable to disposal by trickling filter, primary sedimentation or complete treatment. There were differences in the coliform counts and also chemical differences undoubtedly due to the three types of treatment, but it has long been known that a stream recovers biologically before it recovers otherwise, and such was the case here.

Correlation between Plankton Findings and Other Data - The third objective, correlations between plankton life and other sanitary indices, was not expected to be achieved for all plankton types. But for some species or groups it was well defined. For certain species or groups of species, as shown by the Chrysophyceae in Figure 1, there was an abrupt drop in population at Shadeville, followed by a gradual rise downstream, with a tendency for the population curve to flatten out or decline in the lower part of the river. Since this figure is based on weekly counts of the organisms present at 13 stations over a river length of 118 miles, and covering 30 consecutive months, such distribution may reasonably be assumed to reflect the response of the organisms to conditions obtaining in the river. The drop at Shadeville is unquestionably a response to the pollution there. It may be a response to some particular phase of the pollution, but certainly to the sewage plant effluent. As pollution abates downstream, due to dilution, biochemical action, etc., numbers once more increase. Organisms behaving thus over a period of time may therefore be used as indicators of unpolluted water, when present in large numbers. It must be emphasized, however, that evidence should not be adduced from one sample, because a flowing stream is an ever-changing environment, and because the phenomenon of "blooms" of aquatic microorganisms - those sudden appearances of enormous but transient populations - are so little understood.

Only two whole groups of organisms, the Chrysophyceae or yellow flagellates and the Cryptophyceae or olive-green flagellates, behaved as shown in Figure 1, in the Scioto. In other groups, individual species or genera showed diverse reactions. Figure 2 shows the behavior of one genus and two species of diatoms (Bacillarieae). Asterionella formosa reacts adversely to sewage pollution; Nitzschia acicularis, while at least indifferent to the degree of pollution at Shadeville, still

Fig. 1

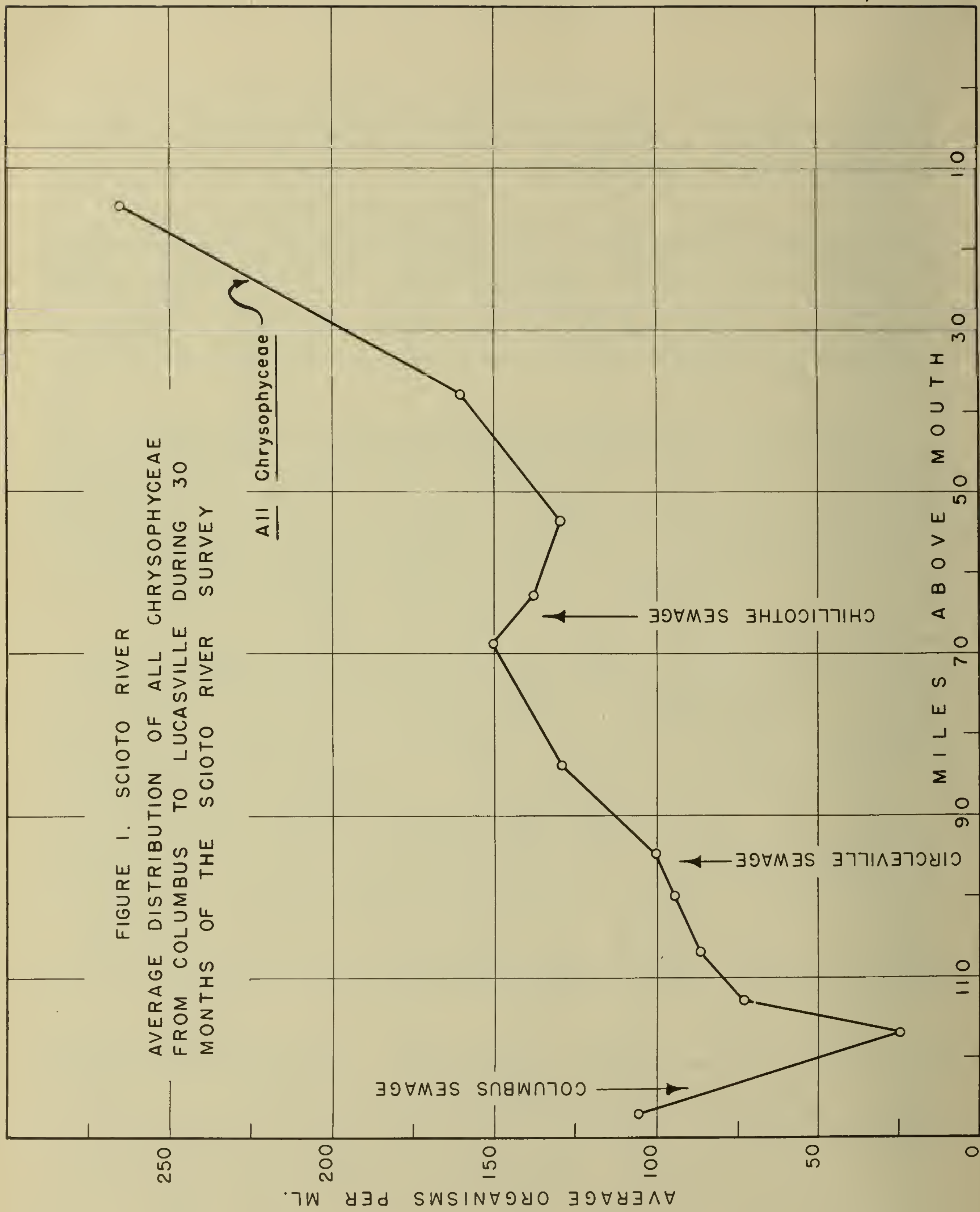

FIGURE I. SCIOTO RIVER
AVERAGE DISTRIBUTION OF ALL CHRYSOPHYCEAE FROM COLUMBUS TO LUCASVILLE DURING 30 MONTHS OF THE SCIOTO RIVER SURVEY

thrives best in clean water. Navicula spp, however, shows a great increase in the polluted zone, which is apparently reflected by the less degrees of pollution at Circleville and Chillicothe.

It is a virtual impossibility to distinguish the species of this genus in survey work. But it has been well established, by Kolkwitz(4) and others, that some species of Navicula apparently prefer polluted water while others attain their maximum development elsewhere. Such a polymodel curve as in Figure 2 might well result from counting two or more indistinguishable species.

Figure 3 shows the distribution in the Scioto of a typical organism which favors sewage-polluted water as a habitat - Sphaerotilus natans, the sewage fungus. Figure 4 shows the behavior of certain species of Euglena in the Scioto. As a rule, members of this genus tend to be abundant only when the temperature is high, hence these average figures for all months of the year are low. Figure 4 includes those members of the genus which tend to be most abundant in polluted water. Euglena oxyuris apparently favors organic pollution also, but its members were rarely large. Conversely, some members of the genus, E.mutabilis, E.spirogyra, are rarely, if ever, found in polluted water, while great blooms of E.polymorpha and E.sanguinea have been noted in unpolluted situations. The highest averages for the species shown in Figure 4, however, are not in the badly polluted zone but in river stretches where there has been an increase in D.O., with a drop in B.O.D. and coliform counts. In other words, the highest numbers tend to appear in the zone of nitrogenous oxidation and not in the zone of carbonaceous oxidation.

It is perhaps unfortunate that, in this biological study, conclusions are drawn from the distribution of suspended forms almost to the exclusion of bottom forms, but physical limitations compelled this. There is little doubt, for example, that the peak of the diatom Navicula at Shadeville is influenced by the numbers swept off the bottom of the very large riffle just above this point. Riffles tend to be liberally carpeted with diatoms at times, and since some of them are swept into suspension by the current, a peak such as the one at Shadeville could be misinterpreted. It could be due entirely to the fact that the physical nature of the substrate at that point favored the growth of diatoms and the current swept them into suspension, where they were readily available for counting, whereas both the mud bottom and decreased current at a lower station militated against a high count. In such a case, pollution might not even be a factor in the distribution of this genus of diatoms.

Fig. 2

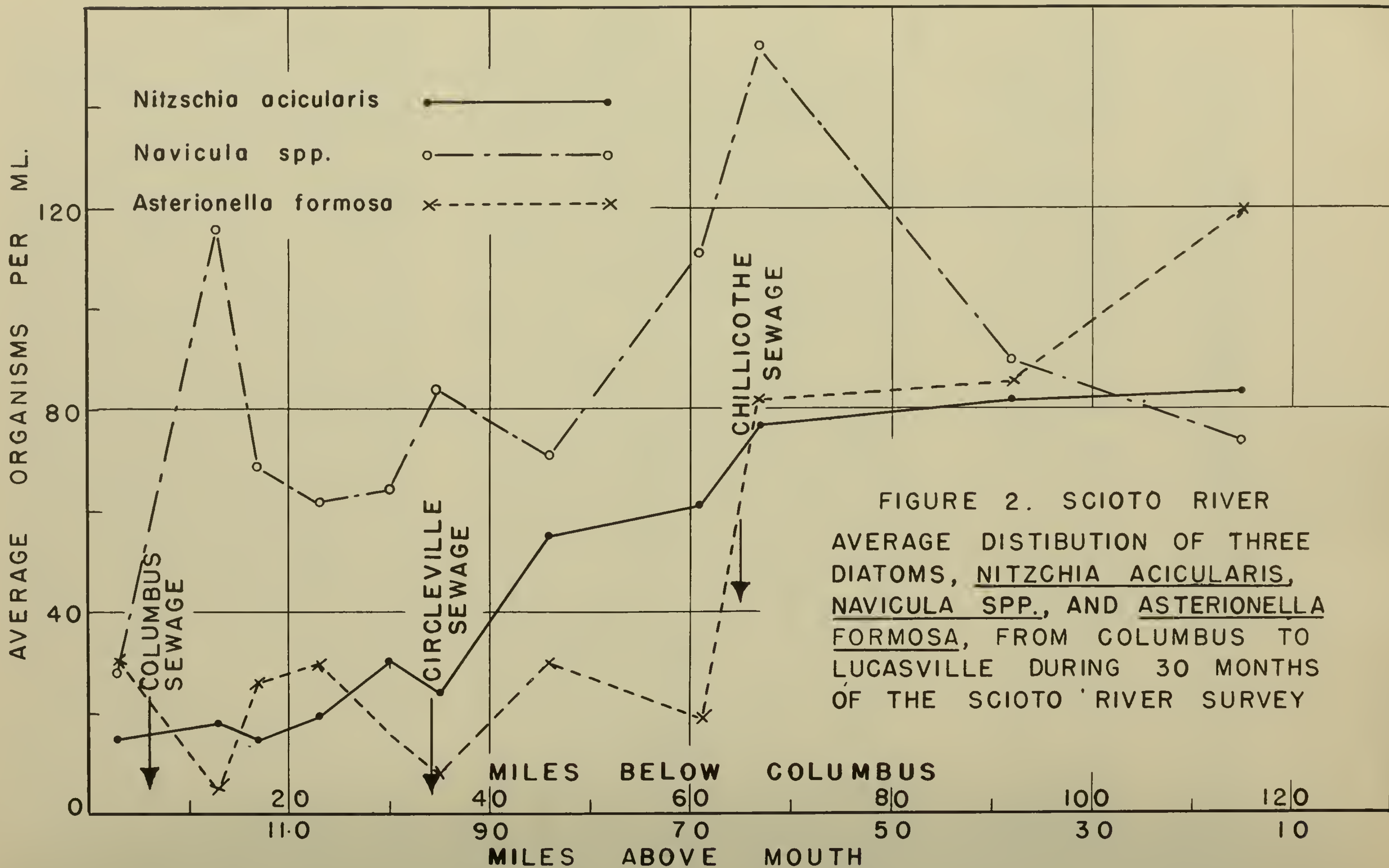

FIGURE 2. SCIOTO RIVER

AVERAGE DISTIBUTION OF THREE DIATOMS, NITZCHIA ACICULARIS, NAVICULA SPP., AND ASTERIONELLA FORMOSA, FROM COLUMBUS TO LUCASVILLE DURING 30 MONTHS OF THE SCIOTO RIVER SURVEY

Fig. 3

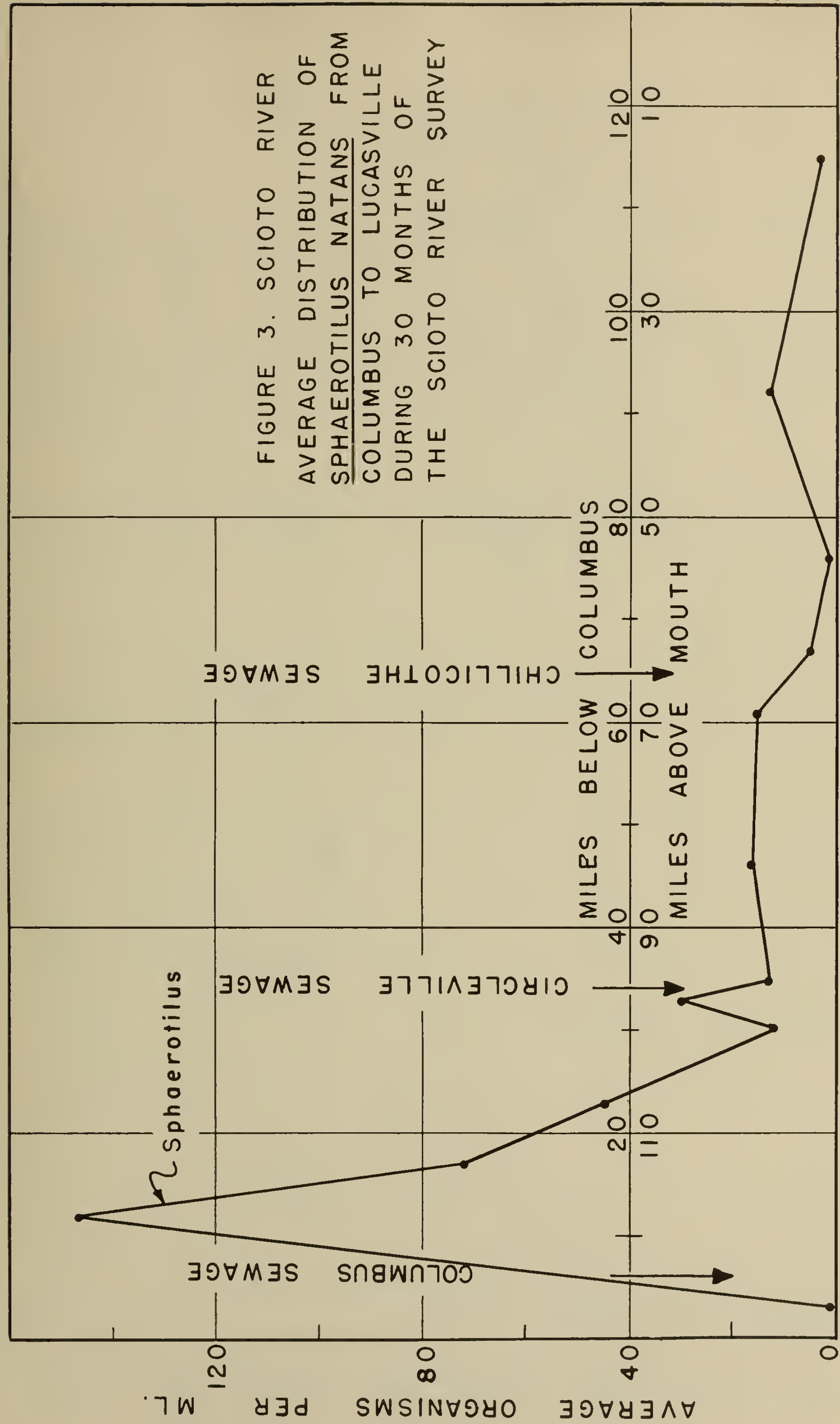

FIGURE 3. SCIOTO RIVER
AVERAGE DISTRIBUTION OF
SPHAEROTILUS NATANS FROM
COLUMBUS TO LUCASVILLE
DURING 30 MONTHS OF
THE SCIOTO RIVER SURVEY

Fig. 4

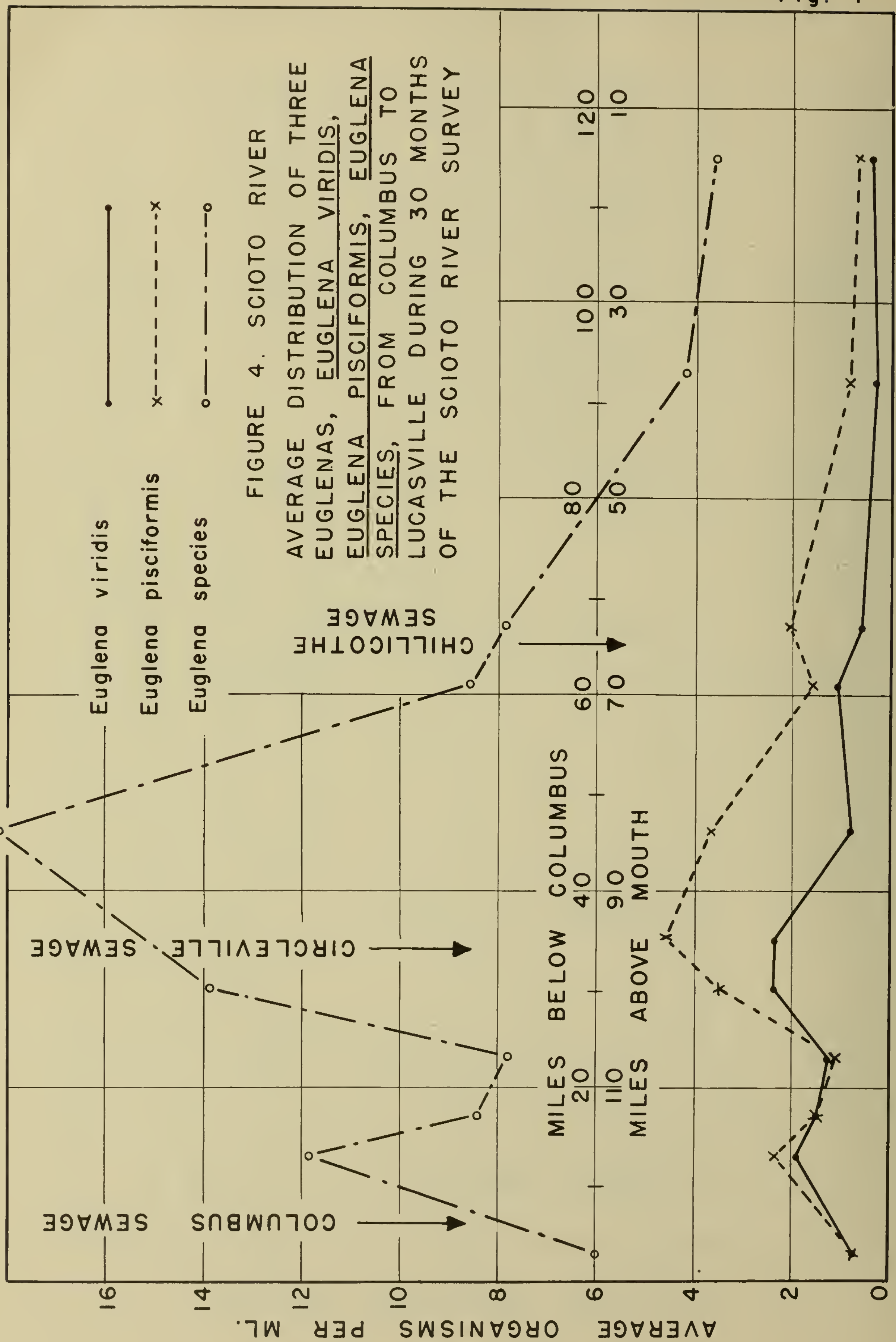

FIGURE 4. SCIOTO RIVER
AVERAGE DISTRIBUTION OF THREE EUGLENAS, EUGLENA VIRIDIS, EUGLENA PISCIFORMIS, EUGLENA SPECIES, FROM COLUMBUS TO LUCASVILLE DURING 30 MONTHS OF THE SCIOTO RIVER SURVEY

Conclusions

While the many factors influencing biological life demand extreme caution in the interpretation of results, certain facts seem fairly well established.

(1) Some organisms tend to be abundant, in their season, in river stretches where the water is of good sanitary quality. These include members of the Chrysophyceae, the Cryptophyceae, a few Cryptophyceae, some diatoms, and a few of the ciliate protozoa.

(2) Other organisms, notably fungi, certain bacteria, some species of Euglenophyceae, some species of Volvocales, and ciliates generally, if present in abundance, in their season, are reasonably indicative of recent organic pollution.

(3) Many organisms, abundant in sewage-disposal plants or foul pools, are not common to the Scioto at any point, but their absence may be due to insufficient organic pollution, or to the fact that they are primarily bottom-dwelling, creeping or crawling forms.

(4) The vast majority of plankton organisms in the Scioto are not found in either the most polluted section or the cleanest section of the river. This is probably not due to any specific ecologic factors in these regions, but rather to the fact that these organisms are tolerant of a wide range of environment. It should be apparent that either gross pollution or extreme purity of water represent much more circumscribed environments than the region in between these two. This region of course includes the region of nitrogenous oxidation, but laboratory experiments for the most part fail to show any marked dependence of organisms of this region upon the existence of other than extremely small quantities of available oxidizable nitrogen.

(5) A well defined seasonal succession is apparent for many of the Scioto River species. Some are most abundant in winter, others in the spring, but the great majority are most abundant in the late summer. This is far more apparent for phytoplankton than for zooplankton, as shown by Figures 5 and 6. This seasonal succession is probably influenced by dilution, clarity of water, increased illumination and other factors, as well as temperature, but too much stress cannot be laid on any single factor. For example, the same seasonal succession occurs

in pools or lakes, where clarity due to silt and dilution vary but little during the yearly cycle.

(6) Plankton production in the Scioto is extremely high, as compared with other rivers which have been investigated. Inevitably this is due in part to fertilization by the organic (and other) wastes of its densely populated basin, but there are other factors which cannot be discounted, as age of water. Nor can the fact be discounted that enormous, if transient, populations occur in pools which receive almost no drainage, or known organic pollution.

(7) More species have been found in the Scioto than reported from any other river in available literature. The species list is believed to be fairly comprehensive, as well as representative for rivers of a comparable class. In part at least, the increased species list is believed due to improvement in the technique of examination.

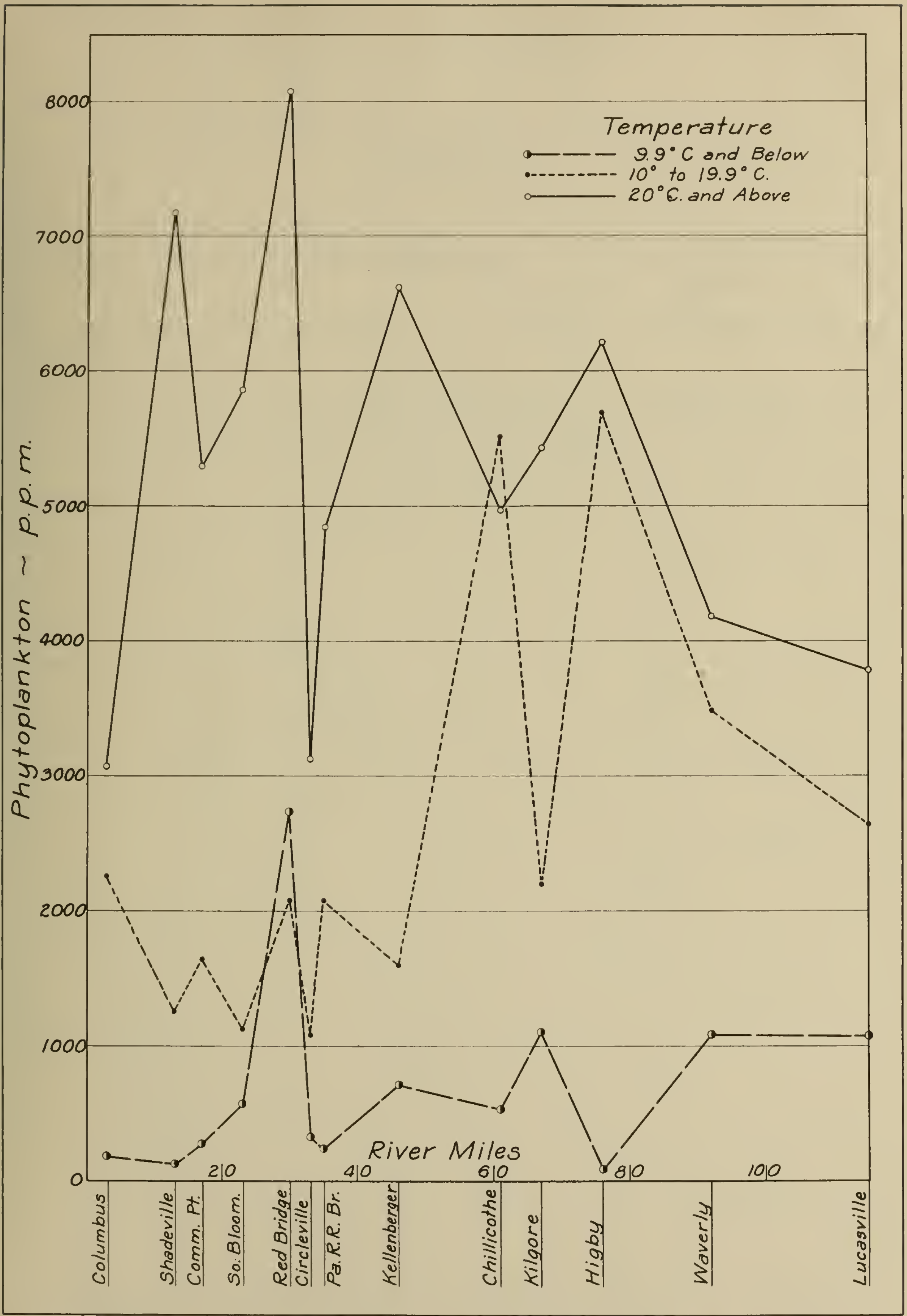

FIGURE 5. SCIOTO RIVER - PHYTOPLANKTON IN PARTS PER MILLION BY VOLUME AT EACH STATION DURING LOW FLOWS FOR THE THREE TEMPERATURE RANGES.

Fig. 6.

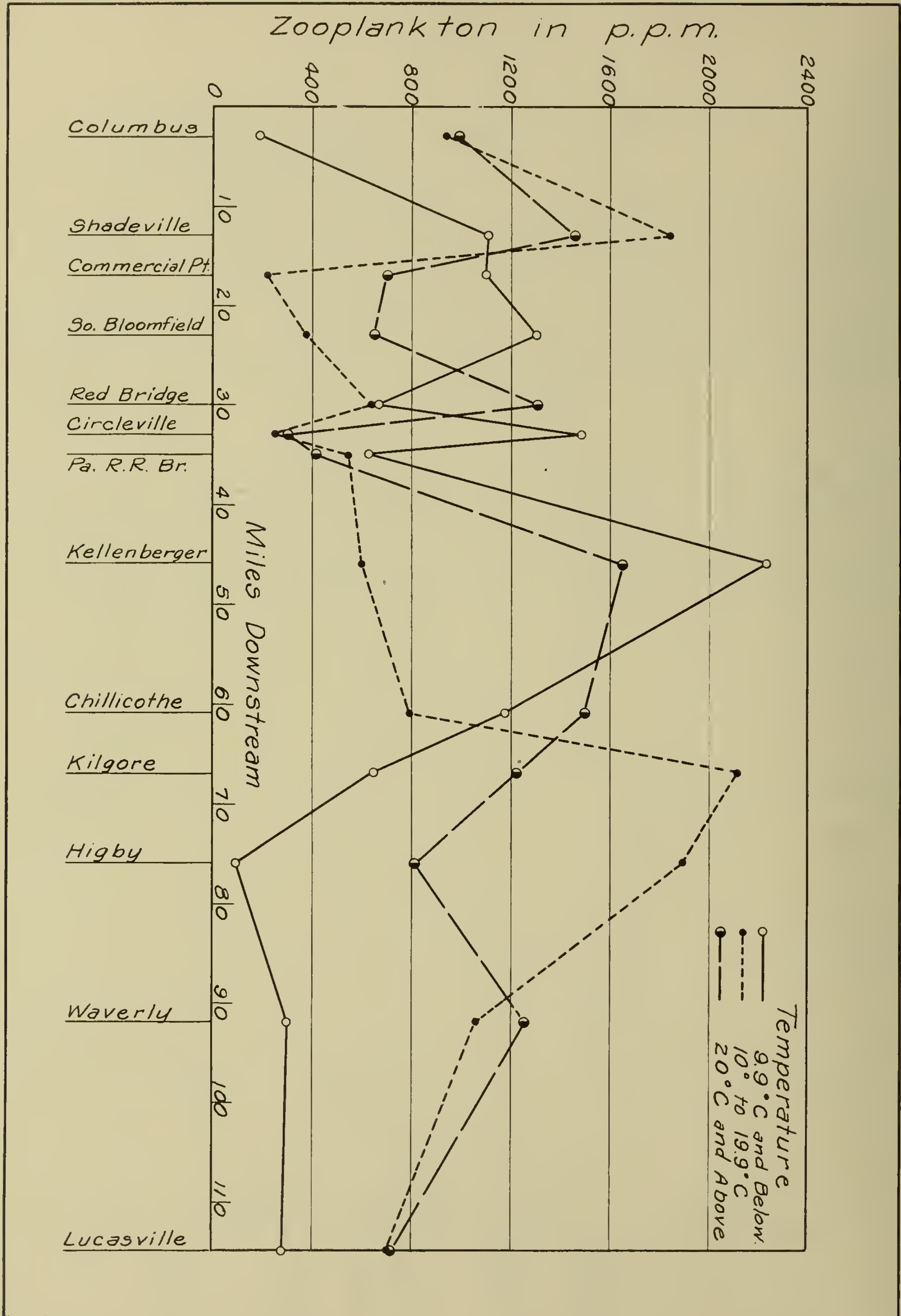

FIGURE 6. SCIOTO RIVER – ZOOPLANKTON IN PARTS PER MILLION BY VOLUME AT EACH STATION DURING LOW FLOWS FOR THE THREE TEMPERATURE RANGES.

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A P P E N D I X II

DISCUSSION OF THE BIOLOGY AND POLLUTION OF THE TENNESSEE RIVER

DISCUSSION OF THE BIOLOGY AND POLLUTION OF THE TENNESSEE RIVER

The Tennessee River receives runoff from an area of 40,600 square miles, draining portions of the following seven southern states: Virginia, North Carolina, Tennessee, Georgia, Alabama, Mississippi and Kentucky. The character of the valley varies from the steep forested slopes of the Pre-Cambrian formations in the east, through the gently rolling calcareous deposits of the Cambrian in the main valley to the Pennsylvanian of the Cumberland Plateau. The runoffs from each of these areas have a decided effect upon the general appearance, biology, and mineral constituents of the Tennessee River and its tributaries.

The river itself is rapidly becoming a chain of impounded lakes or reservoirs from its mouth to Knoxville, 650 miles upstream. Seven of the nine run-of-the-river dams are in service and the two remaining dams, the Kentucky Dam near the mouth and Fort Loudoun Dam just below Knoxville, are under construction. There are now thirteen TVA-operated dams on the tributaries which provide storage as well as additional power. Five more such dams are under construction. In addition to these, there are six major privately owned and operated hydroelectric plants and a number of smaller developments (see attached map of the Tennessee River System). Such developments forming reservoirs in a normally free-running stream are accompanied by a series of biological readjustments to the change from lotic to lenitic conditions.

Another factor having a direct bearing upon the biology of the Tennessee River System is the pollution received from the municipalities, industries, and the organic matter and silt washed from the land itself. In general, the area is predominantly rural, having but few large cities. The three largest cities, Chattanooga, Knoxville and Asheville, account for approximately one-half of the sewered population of about 590,000. It is estimated that about twenty per cent of the domestic sewage receives treatment and that much of this treatment is ineffective due to obsolete and overloaded plants. There are now

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a few highly developed industrial areas, chiefly in the eastern section of the Valley. The industrial activities, however, are becoming more numerous and widespread due to the large amount of available power, raw materials, and to the need of additional capacity of plants producing essential war materials. There are perhaps three main types of wastes now present as classified by their effect upon the aquatic life.

The first type of waste consists of those exerting an oxygen demand on the stream. In the normally clean streams in the Valley the ratio of the amount of dissolved oxygen to the five-day B.O.D. may at times exceed seven. This ratio decreases as pollution is added, passing Streeter's limit of one, which is considered necessary for the maintenance of favorable conditions, to reach a very low value in the more polluted sections. The sections in the main river below Knoxville and Chattanooga are polluted by domestic sewage and industrial wastes. The D.O.-B.O.D. ratio for the section below Knoxville has fallen below one for short periods of low flow, but below Chattanooga it has remained well above this value.

The French Broad River below Brevard is highly colored and polluted by paper mill wastes. Here the D.O.-B.O.D. ratio was found to be slightly more than one, but the color persists for a considerable distance downstream. At Asheville, the stream receives domestic sewage and the industrial wastes from a large viscose rayon plant. The rapid turbulent flow below this point results in a high D.O.-B.O.D. ratio. The river receives another large load of pollution from the Pigeon River, originating at a pulp and paper mill at Canton, North Carolina. This stream is black all the way to its mouth, and contains less than one p.p.m. of D.O., even below Waterville Lake. The effect on the French Broad is to lower the D.O.-B.O.D. ratio to about 1.5 just below the mouth of the Pigeon River and to color the entire river from that point to its mouth.

Beaver Creek receives a heavy load of untreated domestic sewage and the industrial waste from a paper mill at Bristol. This stream is dark-colored even at its mouth and is septic in stretches, but near its mouth has a D.O.-B.O.D. ratio well above one; however, it does influence the South Holston into which it discharges by reducing the ratio from around seven to less than two at critical periods. At Kingsport the South Holston again receives domestic sewage, and industrial wastes from a large chemical and acetate-cellulose plant and a paper mill. Below these wastes the ratio is consistently below one during the summer season, and the stream does not entirely recover before it enters Cherokee Reservoir 35 miles below.

Emory River at Harriman, Tennessee, receives the untreated domestic sewage from that town, wastes from a hosiery mill and from a paper plant. The ratio of D.O.-B.O.D. is reduced by these wastes from about 10 to less than one and the black color extends down this arm of the lake to the main body of Watts Bar.

Scott Creek receives a heavy load of industrial wastes from a tannery and paper mill at Sylva, North Carolina. It is highly colored and almost devoid of oxygen and seriously affects the Tuckasegee River. The D.O.-B.O.D. ratio of this stream twenty miles below Scott Creek is less than one, and the wastes color the Little Tennessee River, into which the Tuckasegee River discharges, from that point to its mouth.

This briefly describes the most important sections polluted by Type 1 wastes. The second type consists of those wastes which materially lower the pH of the waters. In this classification belongs the drainage from the abandoned coal mines of the Cumberland plateau. The waters of the Clinch and Powell River systems, draining such wastes, are highly acid until they leave the Pennsylvanian region and enter the Cambrian where the acid is neutralized by the lime formations. Another stream which is highly acid, due however to the wastes discharged from a copper refining plant, is the Ocoee River. The pH of this stream has been as low as 4.5 at times.

The third group is chiefly composed of silt and minerals in suspension. Most of the streams draining the more developed areas carry considerable amounts of silt. However, there is one stream, the Duck River, which receives large amounts of silt from the phosphate washing plants near Columbia, Tennessee. It has been reported that this material has at times killed large numbers of fish.

The Tennessee River has a high biological productivity, as is evidenced by the qualitative and quantitative abundance of its fishes. With the impoundment of the main stream reservoirs, the production of fish has beengreatly increased. Standing populations of over 800 pounds per acre have been recorded on the lower reservoirs. A valley-wide survey of fishes has to date taken 83 genera containing 174 species comprising 186 forms. These include 12 species of game fishes, 11 species of pan fishes, 10 species of food fishes, and 18 common species of coarse fishes, as well as many other species of coarse and forage fishes. These fishes are important to the Valley from a recreational, economic, and public health or nutritional standpoint. A census conducted in 1940 showed that commercial fishing with set lines yielded well over a

million pounds in the four lower reservoirs alone. This fishery supported wholly or in part over 1300 people on the three lower reservoirs. Fishermen counts made in 1940-41 indicate that the four lower reservoirs annually supported 1,200,000 man-days of fishing, a large part of which was fishing for food. Thus the fisheries of the Valley constitute a valuable source of meat and play an important role in the nutrition and health of the people of the Valley.

In comparison with other rivers of comparable size, the lower portion of the Tennessee River is relatively free of pollution, the most serious effects of pollution being largely confined to the main tributaries in the upper end of the Valley. The biological effects of pollution of the Tennessee River may in general be attributed to the three types of pollutants previously described: (1) Those which bring about oxygen depletion and eliminate all organisms except those which can survive under anaerobic conditions; (2) Those which produce excessive acidity or otherwise directly toxic conditions and thereby eliminate all fish and other dominant organisms; (3) Those which bring about an excessive amount of silting and decrease or eliminate aquatic life through the mechanical effects of smothering and the destruction of the natural habitat.

An outstanding case of the effects of gross pollution on the Tennessee watershed is that of the Pigeon River. The effluent from a large paper mill enters the headwaters of this stream. All fish life has been eliminated for a distance of approximately 25 miles, and the bottom fauna confined to those forms which can live under anaerobic conditions. In the remaining distance of about 40 miles to the junction with the French Broad River, the bottom fauna and the fish life is confined to a few species which are tolerant to pollution. Carp,common suckers, and a few minnows are the only species left of a once rich fish fauna. This condition prevails even though the stream drops 1300 feet in the last 40 miles and receives abundant aeration.

Hyperacidity due to coal mine wastes has totally destroyed the fish life and insect fauna in some of the streams tributary to the Emory and Clinch Rivers.

Silting in the Ocoee River due to mine waste and erosion has filled pools, covered riffles, and destroyed many fish-producing areas.

The reservoirs of the Tennessee System may in general be divided into two types, tributary reservoirs and run-of-the-river reservoirs.

The tributary reservoirs are located on tributary streams in the upper part of the Valley. They have a decided chemical and thermal stratification and little river influence, because of the relatively large storage volume in comparison to the inflow. Also, these reservoirs are usually characterized by the formation of density currents which at times cause a rather complex stratification (Wiebe, 1940). They usually have one major fluctuation each year, the water level being high during the spring and summer and low during the fall and winter, water levels frequently varying as much as 100 feet during the year.

Because of the clearness of the water and the typical lenitic conditions produced by storage of practically all inflow during the spring and summer months, the tributary reservoirs have a higher population of plankton than the run-of-the-river reservoirs. Due to the wide annual fluctuation, the aquatic vegetation which normally occupies the littoral zone of lakes is absent from these reservoirs, and the bottom fauna is greatly reduced. Such bottom fauna as is present is largely confined to the hypolimnion and is mainly restricted to such forms as oligochaet worms, chironomids, and Chaoborus, which can exist under the anaerobic conditions which frequently occur there.

The fish population of the tributary reservoirs differs from that of the run-of-the-river reservoirs in having a higher relative abundance of game species but a lower total population in pounds per acre. Because of the clear waters, smallmouth bass, black crappie and wall-eyed pike predominate.

The run-of-the-river reservoirs are located along the main channel of the Tennessee River. In general these reservoirs may be divided into three sections: an upper third where the water is confined primarily to the original channel; a middle third where the water overflows the original banks (natural levees) of the stream; and a lower third where the lake extends to the fairly steep margin of the river flood plain. Because of their relatively small volume in relation to inflow and outflow, river conditions predominate and there is seldom any chemical or thermal stratification. In addition, the water of these reservoirs is generally more turbid than that of the tributary reservoirs, becoming quite muddy during flood conditions.

Under normal conditions, in the upper sections of these reservoirs there is always a perceptible current and the water is more turbid than in the lower sections; likewise, each reservoir is generally less turbid than the one next above it and silting is correspondingly reduced. The over-all fluctu-

ation of water level is much less than on the tributary reservoirs, usually ranging from 2 to 10 feet in different reservoirs. In summer there are frequent minor fluctuations in water level coupled with a gradual seasonal drawdown extending into the winter period. Turbidity, fluctuation, and other factors such as the activity of certain coarse fishes, greatly inhibit the growth of aquatic vegetation.

The plankton population of the run-of-the-river reservoirs is highest in the clear water of the low sections, and is lowest in the upper sections where current and turbidity are more pronounced. In general, in passing from one reservoir to the next lower, an increased production of plankton is correlated with the decreased turbidity. The greatest production of plankton occurs during the early winter when the flow is largely composed of clear water from the tributary reservoirs.

Bottom fauna is much more varied and abundant in the run-of-the-river than in the tributary reservoirs. The predominant forms in order of their relative abundance as determined by volume are Ephemeroptera, Chironomidae, Chaoborinae and Oligochaeta. The mayflies, which consist chiefly of one species, *Hexagenia bilineata*, reach their greatest abundance just below the lower limit of the zone of fluctuation, and in silty bottoms may extend to depths of 30 or more feet. The phantom midge, *Chaoborus*, and the oligochaet worms are largely confined to the deeper waters in the silted lower sections of the reservoirs. Chironomids are numerically more abundant than any other form and occur from the shallow to the deep waters. Certain of the smaller species are apparently well adapted for existence in the zone of fluctuation, where they reach their greatest abundance; other larger species attain their greatest abundance in the deeper waters of the lower sections of the reservoirs. In general, the forms which occupy the zone of fluctuation are those having a short life cycle or well developed powers of locomotion. Among these the most important appears to be the corixid, *Trichocoriza burmeisteri*, which attains tremendous abundance in the shallow waters and constitutes an important item in the food of certain species of fish.

The standing population of fishes is much greater in the lower reservoirs than in the tributary reservoirs. Game fishes comprise a lower percentage of the total population than in the storage reservoirs because environmental conditions favor the coarse species.

Among the 9 species of game fishes occurring in the lower reservoirs, largemouth bass, white bass and the sauger are the most important in the order named. Pan fishes are numerically more

abundant than the game fishes, and although 11 species occur in the area, crappie and bluegills comprise almost the total catch. The most important food fishes are the catfishes, drum and the spoonbill sturgeon. A large number of coarse fish occur in the lower reservoirs, the most abundant being carp, buffalo, gizzard shad and gar. In the backwater areas these coarse fishes may make up 70 to 85 per cent of the weight of the total fish population.

The Tennessee River at its mouth is considered a clean stream. It is normally clear, has very low bacterial counts and B.O.D., and the plankton are those usually observed in clear waters having very little organic material.

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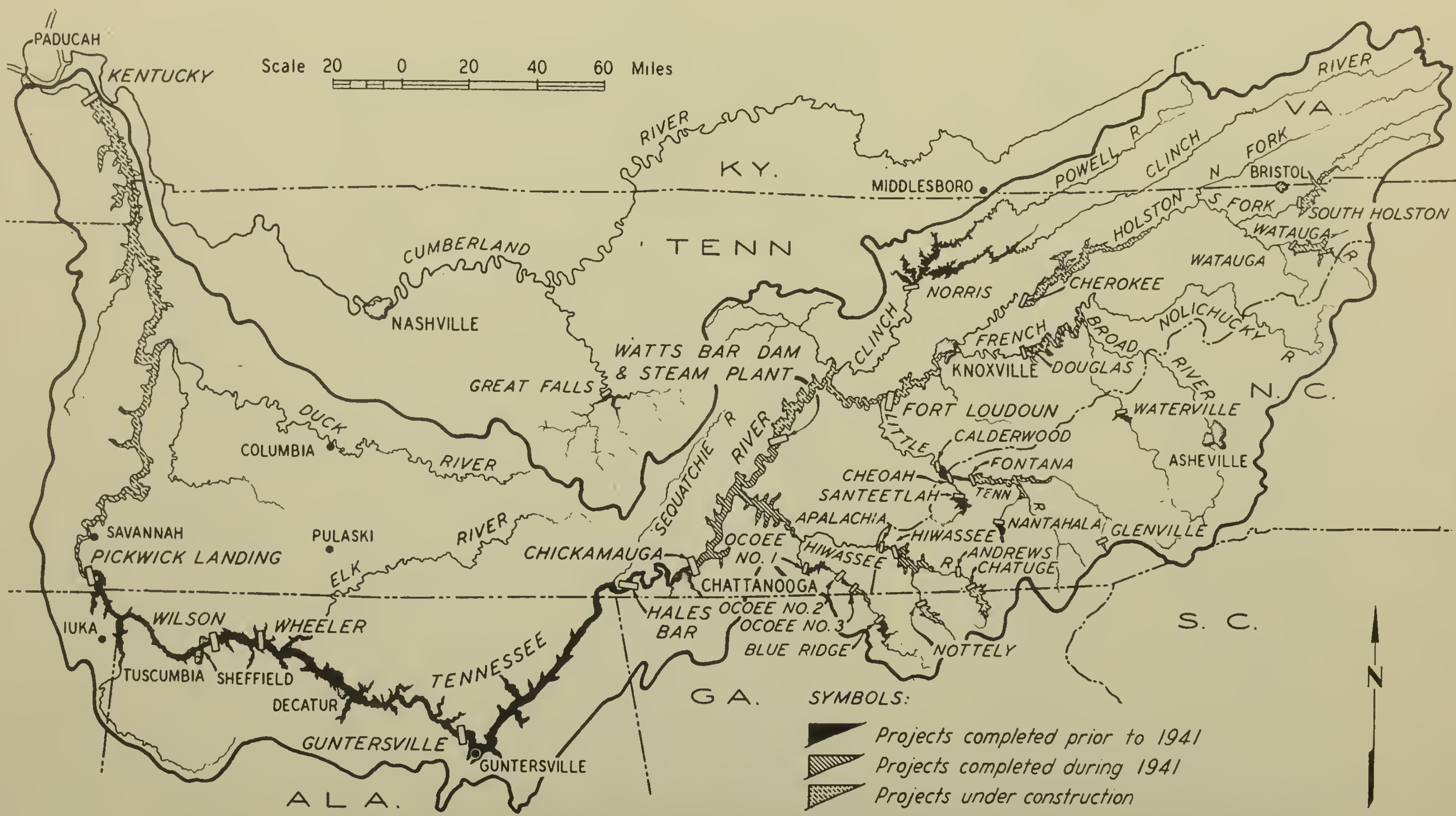
MAP OF THE TENNESSEE RIVER SYSTEM



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